**Overview**

**Diffusive Shock Acceleration (DSA)**

1. The acceleration of charged particle is due to repeated reflections across a shock. This is seen in the reflection at magnetic mirrors, but is applicable for shocks due to the wave-particle interaction at the shock front.
2. The injection energy must be a few times the thermal energy in order to make an initial crossing at the shock front.
3. Thought to be the primary mechanism for particle acceleration at shock waves.
4. Injection problem – particles must have energies significantly higher than the thermal energy in order to cross the shock boundary.

We solve the cosmic ray transport equation in 1D and steady state.

**Database results**

81% of r = 4 upstream distribution converge for $E_{\text{kin}} > 1$ keV. Subdivided results into additional categories and performed statistics:

1. perpendicular, 2. parallel, 3. forward, and 4. reverse

- Spectral ratios have the same general trend regardless of shock direction.
- 48 in excellent category
- 106 (45%) in excellent or good categories
- 52 in r = 1.2 category (softer/harder)
- 72 in < 0.8 category (harder/softer)
- In the last two cases, DSA theory does not predict observations well. There may be either seed populations or additional acceleration mechanisms unaccounted for in this study.

- As the shock progresses, the number of particles at the shock increases. This trend is the same for all categories except for reverse shocks.
- Reverse shocks have decreasing number of particles closer to shock.
- Observations tend to be harder than theory predicts.

- Regardless of the time before shock, the observations show a distribution of slopes which peak at -6.

**Multiple Shock Methodology**

We take the concept of particle acceleration at single shock and extend it to multiple shocks. During solar max, accelerated particles will still be in the system as second shock passes (i.e., non-Markovian process). The model is related to the Box model.

**Model Assumptions**

- CME expands outward with constant background flow velocity, approximately constant diffusion tensor with respect to r, and spherically symmetric
- Box length, $L = 1$ AU, $\lambda = 0.3$ AU, $v_{\text{b}}(\text{at 1AU}) < 0.6 v_{\text{sh}}(\text{at 0.1 AU})$

**Total injected distribution**: $f(p) = \delta(p') + \phi(p')$

1. Accelerate the injection distribution at an interplanetary or CME driven shock using Eqn 2
2. Decompress the accelerated distribution. We solve Eqn 1 by the method of operator splitting. We then have a decomposition method that includes convection, adiabatic decompression, and diffusion, as well as time between shocks.

3. Re-accelerate the newly decompressed distribution and upstream distribution at a subsequent shock wave

- Reverse shocks are not included in these statistics
- 52/56 events did not require additional population to account for downstream distribution
- 19/56 “upstream and previous” events exceeded upper limit cutoff – more than enough particles. There are not necessarily the shocks with smallest $\Delta t$
- 14/56 “previous only” events exceeded upper limit cutoff
- 0 “upstream only” events exceeded 10 keV