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Particle acceleration at shock pair

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Overview

In the solar system, shocks exist in front of all the planets, in the solar corona and also in the solar wind. They are considered as an efficient and important mechanism to accelerate charged particles in solar system(CME, SEP, GLE etc.). The efficiency of the acceleration depends on various conditions, including shock speed, shock geometry, seed population, the shock strength and compression ratio, etc.. A recent study of Ground Level Enhancement (GLE) events (a total of 16) in the solar cycle 23 shows that in these extremely large SEP events, one often finds two or multiple CMEs within a short period (9 hours) of time. This led to the suggestion of the shock pair scenario.

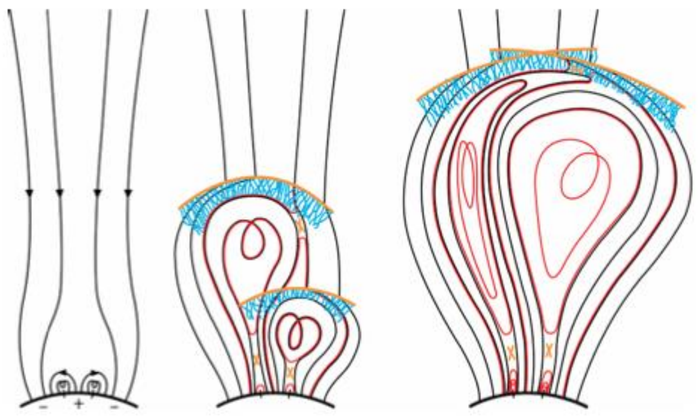

Figure 1: The "twin-CME" scenario for the generation of an extreme SEP event. Two nearby CMEs erupt in sequence. The first CME setup a turbulence enhanced downstream of the first shock. Efficient acceleration then occur as the second shock plow into this medium. Also, the driver material of the first CME can be released to the front of the second shock through magnetic reconnection. This material can be accelerated by the second CME shock as well. From [Li et al., 2012].

We developed a mixed test-particle code which combines the brutal force approach with focused transport approach to model the transport and acceleration of particles in the shock pair. In the system setup, the first shock is at rest(in the first shock frame) and the second shock has a speed moving toward the first shock.

Key Findings

Shock pair plays an important role in particle acceleration is due to the fact the first shock setup a stronger turbulence level and seed population for the second shock. The figure shown below is the simulation results which are the final spectra of parallel shock for both shock pair and single shock. The turbulence level in upstream of the first shock is set to be$(^{\delta B}/_{B})^2 = 0.05$. Then it is increased to 0.8 after across the first shock according to Rankine-Hugoniot jump condition. From the figure, the highest energy from the shock pair is twice as much as from single shock. Also the intensity for shock pair case is 10 times larger than single shock case at the same energy level.

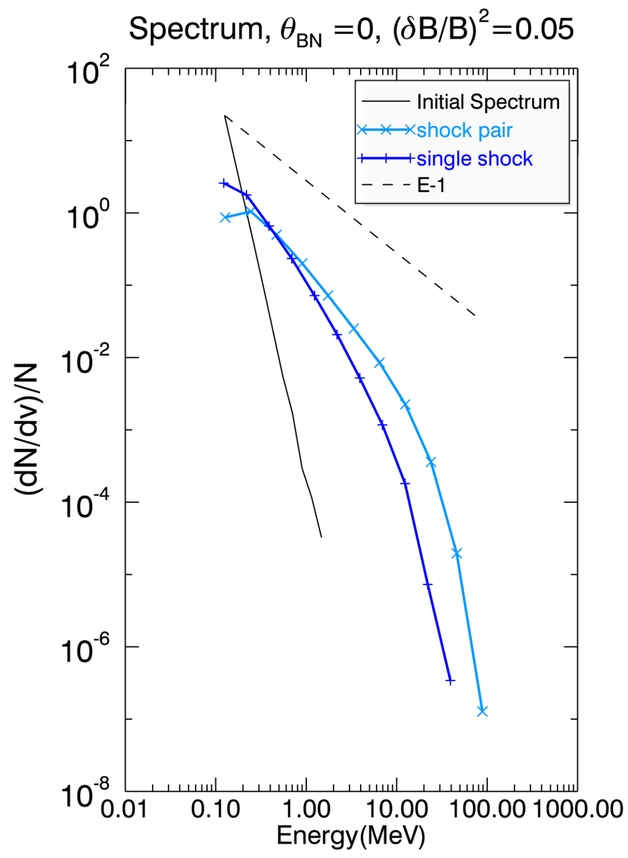

Figure 2:The spectra for both shock pair setup and single shock setup in a strictly parallel shock. Total simulation time 3 minutes. The turbulence level at upstream of first shock is set to be 0.05. All the turbulence and background parameters are scaled up to ~3 solar radius. Particles are injected at ~3 gyro radius from shock at upstream followed an injection spectrum shown in the figure as a black straight line. The black dashed line is predicted shock acceleration spectrum with slope index -1. The blue line with plus sign is the single shock spectrum and the cyan line with cross sign is the shock pair spectrum. Obviously, shock pair setup is much more efficient to accelerate energetic particles.

Explanation

SEP(solar energetic particle) events, especially GLE events, are considered to be hazardous space weather to satellites and astronauts. A huge amount of particles penetrate into earth magnetosphere and ionosphere which would lead to communication interruption. Knowing the mechanism of acceleration would also provide more information in forecasting.

Impact

Although it is generally true that faster shocks can accelerate particles to higher energies, CME observations showed that not all fast shocks (e.g. shock speed > 1000 km/s) can lead to large SEP events. Shock pair scenario provides a different view of shock acceleration and this scenario can also be applied in CIR shock pairs, superflares, etc..

Acknowledgements

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