SUPRATHERMAL ION ACCELERATION IN QUASI-PARALLEL SHOCKS

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1. INTRODUCTION

Collisionless shocks in space plasmas are known to be capable of accelerating particles to very high energies. Particles are accelerated through a process called diffusive shock acceleration (DSA). However, this process requires injection of particles with higher than thermal (suprathermal) energies. This population of suprathermal ions are called the ion seed population.
We have studied the formation of the ion seed population as a result of solar wind ions being reflected off Short Large Amplitude Magnetic Structures (SLAMS) in the Earth's bow shock using data from the four Cluster satellites. Data from FGM, EFW and CIS were used at a time when the separation of Cluster was ~100 km. The short separation results in high time and spatial resolution, which allows for a detailed study of the event.

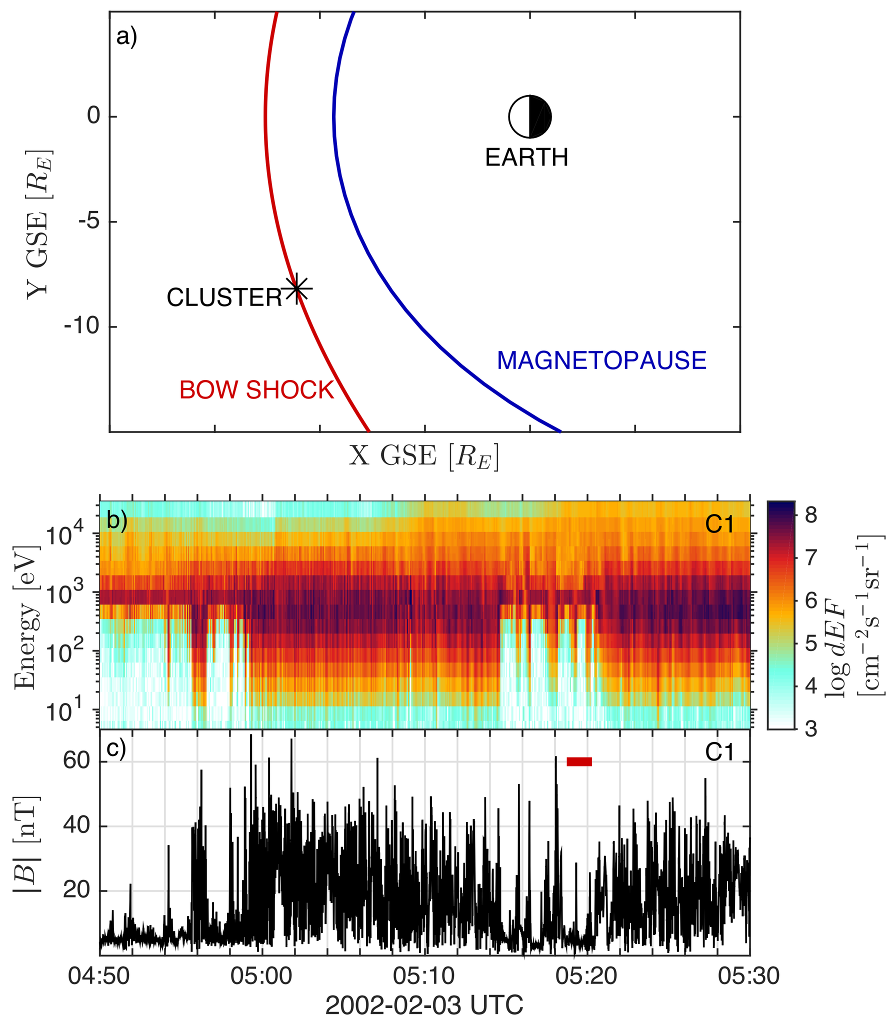

Figure 1. Cluster shock crossing. Panel a): position of the four Cluster satellites. b) Ion differential energy flux. c) Magnetic field amplitude. The ion distribution function is obtained for the time interval indicated by the red bar.

2. OBSERVATIONS

Reflected ion moving in the sunward direction are observed just upstream of two SLAMS. On average, these ions fit a specular reflection well. The energy of the reflected ions is lower because the SLAMS is moving in the anti-sunward direction.

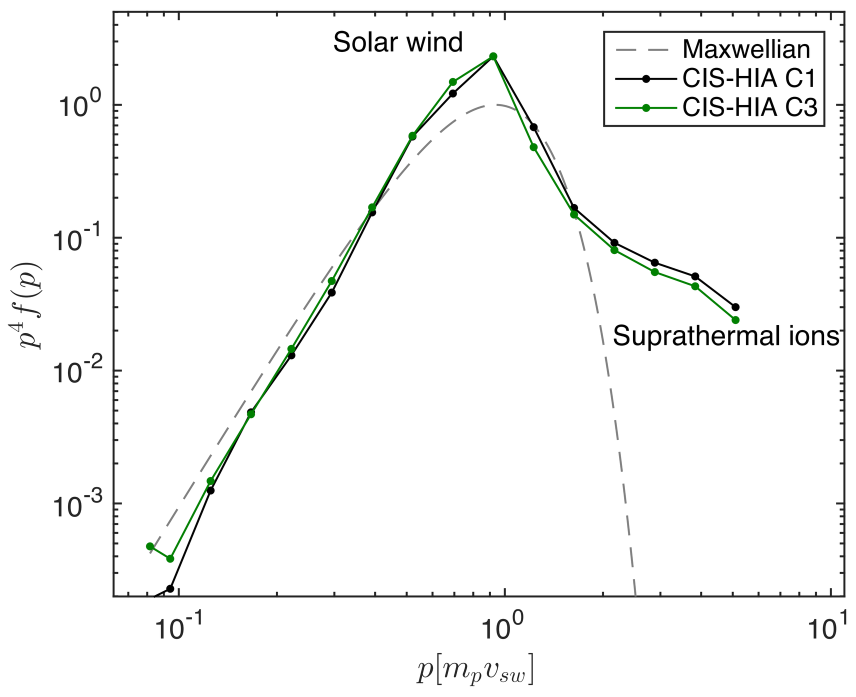

Figure 2. Normalized phase space density for all energy bins of CIS-HIA. A Maxwellian distribution has been fitted to the data. In addition to the thermalized plasma, two other populations can be seen: a colder solar wind, and a suprathermal population.

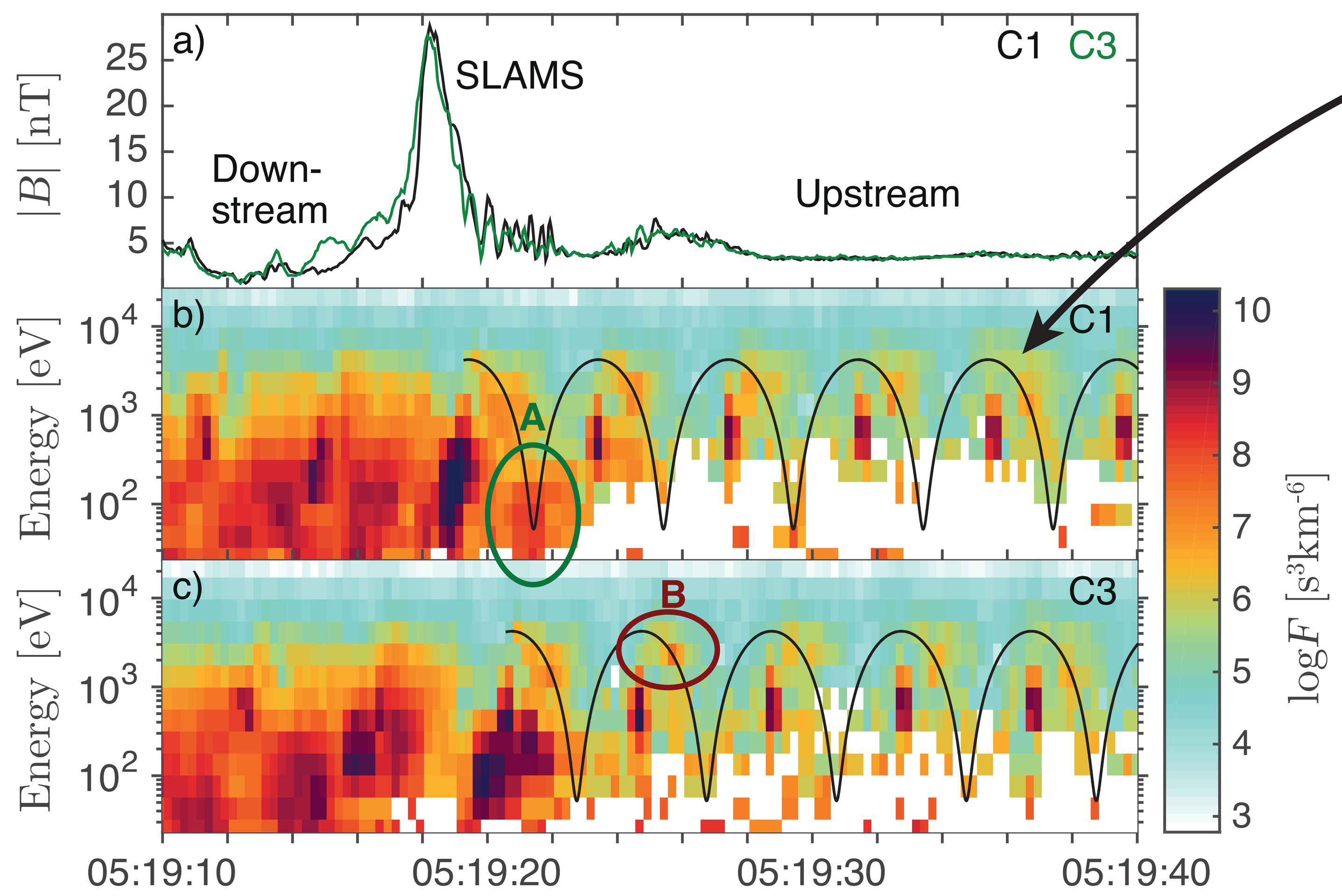

Figure 3. a) Magnetic field amplitude for two spacecraft. b)-c) Ion phase space density integrated over polar angle in subspin resolution. Ion population A: reflected ions just upstream of the SLAMS. B: ions with higher energy than the solar wind, these ions are seen by both spacecraft and further upstream as well. The solid lines in panels b) and c) are theoretical curves for shock drift acceleration from Figure 5.

3. SIMULATION

In order to further study the physical process of reflection, a 1D test particle simulation was performed. The simulation was done in the SLAMS frame of reference and utilized magnetic and electric field data from the SLAMS. The particles had some initial speed $v_{x,I}$ to simulate the solar wind and the particle ended up with a final velocity v_f, after encountering the SLAMS. The simulation showed that solar wind particles with low energy ended up being reflected, while particles with slightly higher energy could pass through the SLAMS and continue downstream.

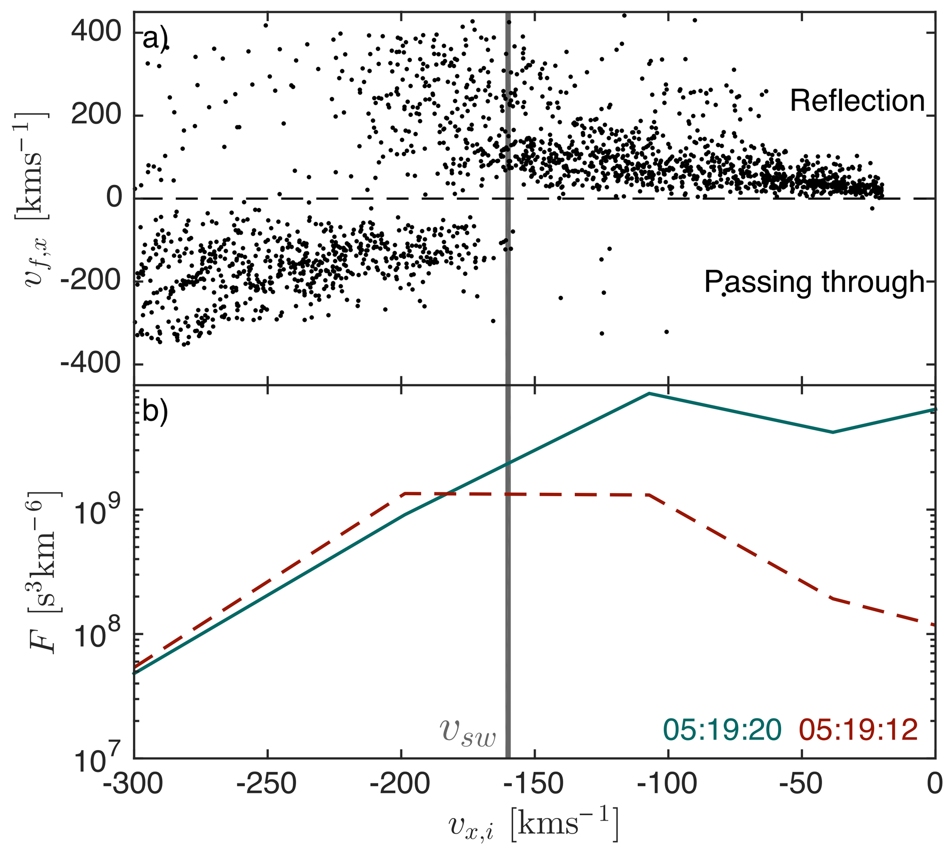

Figure 4. Top panel: simulation results with final velocity as a function of initial velocity. Bottom panel: Phase space distribution of solar wind upstream (blue solid line) and downstream (red dashed line) of the SLAMS.

4. SHOCK DRIFT ACCELERATION

Shock drift acceleration is a process where particles reflected off a shock surface are accelerated by the convecting electric field.
This means that in the solar wind frame or plasma frame, the energy of a reflected particle is conserved. As the particle gyrates in the plasma frame, the energy is increased in the spacecraft frame. This energy curve is shown as a function of time in Figure 3b-c. The ions (marked 'B' in Figure 3) with equal or a few times the energy of the solar wind found upstream of the SLAMS fit this curve well and the curve connects the low-energy reflected ions to the upstream high-energy ions. This indicated that the reflected ions are undergoing shock drift acceleration upstream of the SLAMS.

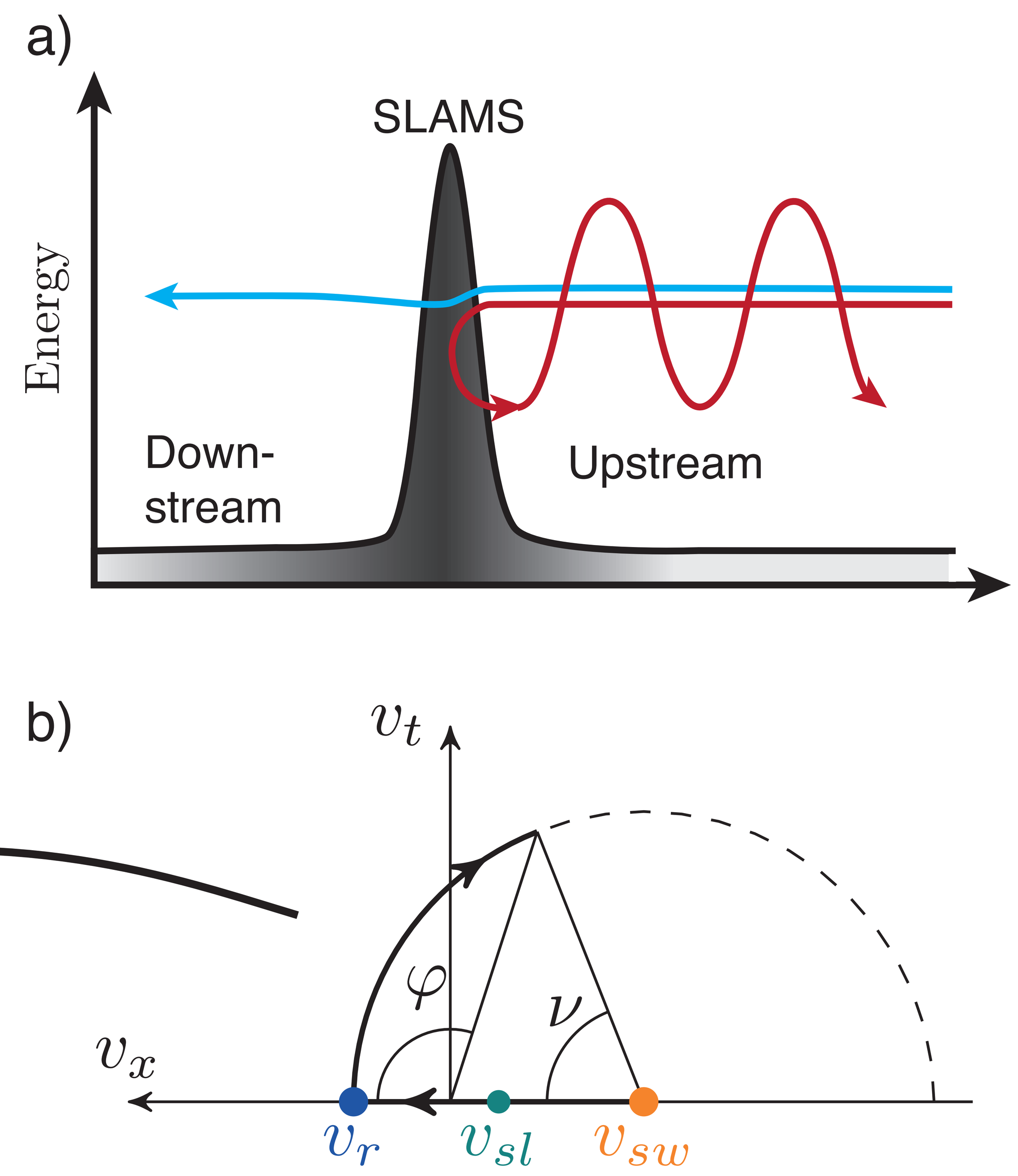

Figure 5. Sketch of the mechanism in real space and velocity space. a) Two solar wind ions impinging on the SLAMS. The ion with higher energy passes straight through while the other one is reflected. The ion undergoes shock drift acceleration upstream of the SLAMS and obtains higher energy. b.) trajectory of the reflected ion shown by the arrows. The ion start in the solar wind and is reflected off a SLAMS. The ion starts to gyrate with a constant speed in the solar wind frame, this is indicated by the dashed half-circle.

5. CONCLUSIONS

We present observational data of solar wind ions being reflected off SLAMS and subsequently undergoes shock drift acceleration.

- Solar wind ions with low velocity are reflected off the SLAMS while ions with higher energy pass through. This is shown by test particle simulations and ion data from the satellites.
- Reflected ions undergo shock drift acceleration upstream of the SLAMS. Ions that fit this model are found upstream of the SLAMS.
- After a few reflections off SLAMS these ions can form the suprathermal ion seed population and be injected into diffusive shock acceleration.

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