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Proton and Helium Pickup Ion Acceleration at the Solar Wind Termination Shock

BIC Project: Invest in TIME - A $4M University of Arizona facility poised for global leadership in interdisciplinary earth hazards research

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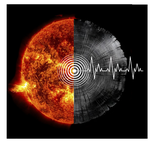

1. Introduction

Tree rings track the behavior of our sun through Carbon-14, produced when high-energy protons collide with Nitrogen-14 in our atmosphere. The amount of Carbon-14 produced is influenced by two aspects of solar activity: 1 - solar geomagnetic shielding allows high-energy particles from cosmic radiation into Earth's atmosphere at different points in the solar cycle and; 2 - bursts of high-energy particles are shot towards Earth when solar flares and coronal mass ejections occur. These high energy particles are accelerated by collisionless shockwaves that are ubiquitous in the solar wind. This work presents simulation results on the acceleration of Proton and Helium pickup ion distributions at and just downstream of the solar wind termination shock. The primary method is numerical integration of equations of motion in a realistic representation of the termination shock. Tracking the phase space states of test particles allows for a prediction of the Helium pickup ion energy distribution. Possible observational comparisons to the ***Voyager*** and ***New Horizons*** missions are discussed.

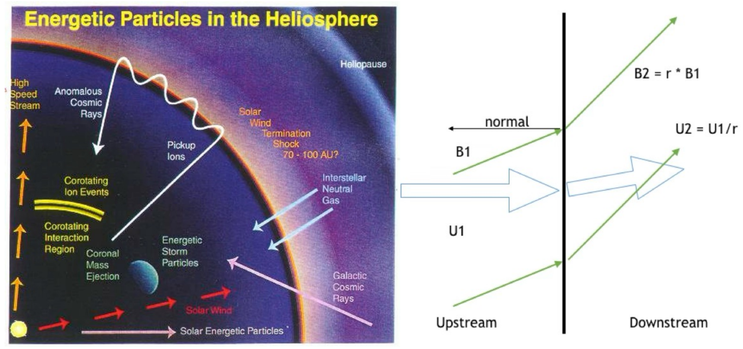

Figure 1.
A representation of the sources and variations of energetic particles in the heliosphere. A diagram of the basic geometry utilized in the simulation. The termination shock is treated as a perpendicular shock in our simulation.

2. Motivation

This work studies the fundamental nature of particle acceleration by shocks in the solar wind. The physics of solar energetic particles is the same as that seen at the edge of the heliosphere The ***New Horizons*** mission is expected to cross the Solar Wind Termination Shock within the next few years [1]. The particle instrument PEPSSI should provide critical data on the energy spectrum of interplanetary pickup ions (PUIs) and anomalous cosmic rays (ACRs) [1,2]. This crossing will provide the latest measurement of such particles since the ***Voyager*** missions [3]. The capabilities of the PEPSSI instrument will allow for a first-ever measurement of the Helium PUI distribution at the edge of the heliosphere.

3. Simulation

The simulation was created using a method similar to that shown by Decker in 1988 [4]. Particle trajectories are only governed by the background fields via the Lorentz force.

$$m\frac{d\vec{v}}{dt} = q(\vec{E} + \frac{\vec{U}}{c}\times\vec{B})$$

The magnetic field is taken as $\overrightarrow{B_i} = B_0\hat{z}$ with a plasma bulk velocity of $\overrightarrow{U_i} = U_{SW}\hat{x}$ where i denotes the fields either up or downstream from the termination shock. We prescribe an advective electric field. The particles are followed in the shock frame explicitly. The termination shock is configured as a discontinuity at x_0 with upstream defined as all positions $x < x_0$ and downstream as $x < x_0$ The magnetic field and plasma flow across the shock are determined by the usual jump conditions.

4. Turbulence

For increased fidelity, inertial turbulence is included [4,5,8]. The turbulence is set with a user-defined variance $\sigma^2 = \delta B^2/B_1^2$ and a coherence length of 1 AU.

$$\overrightarrow{B_i} = <\vec{B}>_i + \overrightarrow{\delta B_i}$$

The fluctuating component of the field is treated as a linear perturbation to the mean field. Circularly polarized, randomly oriented waves are injected into the field to approximate an isotropic energy cascade. The turbulent spectrum is generated once in all three dimensions at the beginning of the simulation and then re-summed at each time step.

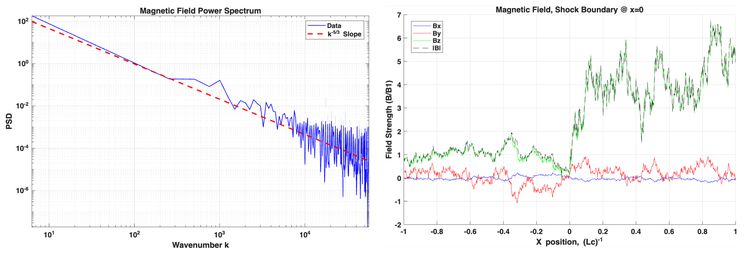

Figure 3.
Plots of the basic trends of inertial turbulence used in the simulation. The right graph shows the components of the B-field between correlation lengths in the simulation. The right graph shows that power spectral density of the upstream turbulence is in line with that as Kolmogorov theory. The collective behavior of the simulated particles can be surmised from their dynamics in the magnetic field configuration shown.

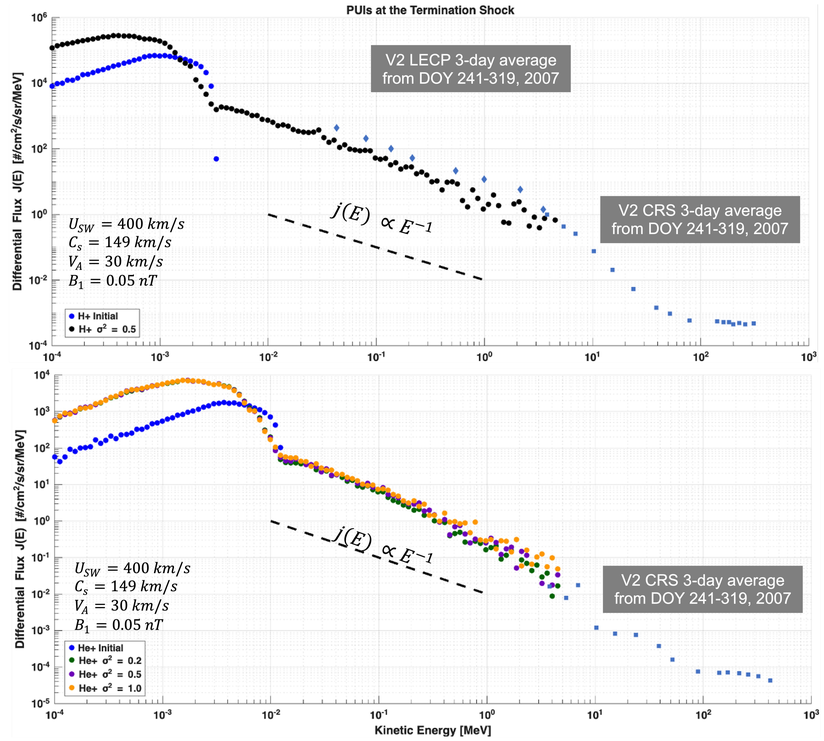

Figure 4
The results of both simulations. The top plot shows the proton simulation. This was made primarily as a validation step. It is shown that the simulated distribution closely follows the observations from Voyager 2. On the bottom, the simulated Helium distribution is shown. The Helium distribution (blue dots) is distinguishable from the proton starting at 5 keV. Both simulations predict the formation of a high energy tail extending beyond the initial distribution, in line with the theory of diffusive shock acceleration [6,7,8,9]. The prediction for Helium PUI shows that the entire distribution will be within the detectable bounds of New Horizons instruments. Simulations were run for an internal time of $10^5\ \Omega_g^{-1}$

5. Results

Figure 3 shows the output of the simulations. A total of 2 simulations were run under the conditions shown on the inside panel of the graph. One simulation for pickup protons; performed as a validation step. Another for pickup helium, the new prediction. The simulation is shown to reasonably recreate the observations of ***Voyager 2*** at the termination shock. The prediction for Helium PUI shows that the entire distribution will be within the bounds of PEPSSI detector onboard New Horizons. These results can be used to interpret the data taken onboard the ***New Horizons*** spacecraft when it crosses the termination shock.

References

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