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Modeling Momentum Diffusion in the Solar Wind

Simulations of Energetic Particle Transport

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Introduction

The solar wind is the steady flow of plasma from the Sun out through the solar system and to the boundary of the heliosphere. Intense solar events such as solar flares and coronal mass ejections energize particles to energies much higher than that of the solar wind. These particles can be very dangerous to astronauts and power grids.

With the launch of Parker Solar Probe (PSP) this summer, scientists in many areas of heliospheric physics are preparing predictions to compare to the measurements the probe will make.

I have used the Energetic Particle Radiation Environment Module (EPREM) [1], which is a part of the Earth-Moon-Mars-Radiation-Environment-Module (EMMREM) which is UNH's radiation dosage predictions website. I have added the effect of momentum diffusion to the code in order to improve the prediction abilities of the code.

Method

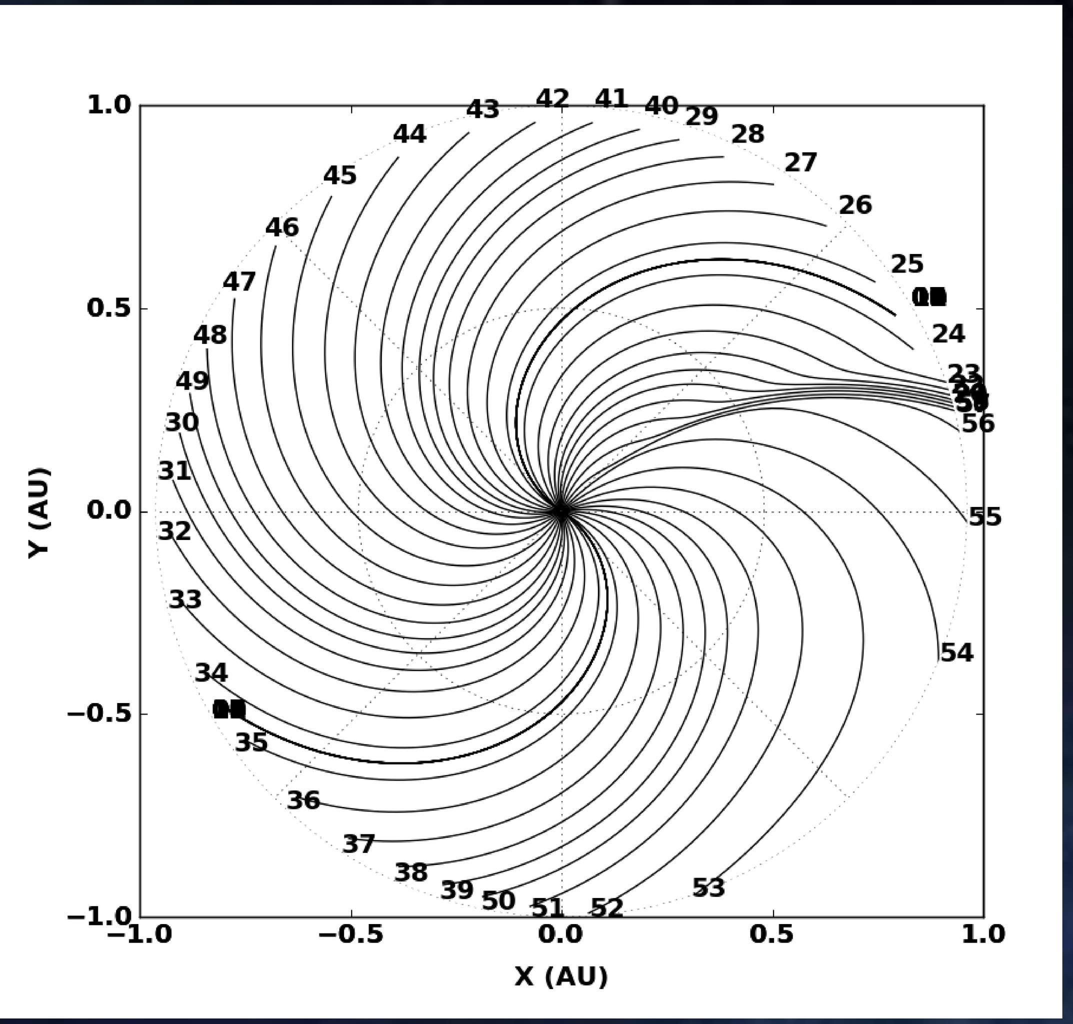
Numerical simulations are a common modeling method in physics, specifically when equations of motion do not have analytical solutions. The EPREM code evolves the distribution function, which describes the particles in the plasma, by adding the changes from many effects over a discrete time step. The solar wind plasma flows outward from the sun as the simulation runs. For momentum diffusion the change in the distribution function has the form [2]:

$$\frac{\partial f_0}{\partial t} = \frac{1}{v^2}\frac{\partial}{\partial v}\left[v^2 D \frac{\partial f_0}{\partial v}\right]$$

$$D(v) \propto v^{\alpha-2}$$

Corotating Interaction Regions

Corotating Interaction Regions (CIRs) are regions where faster wind catches up to the slower wind and creates a compression region as shown below:



These regions excite particles (in particular, pickup ions) that can then propagate back towards the sun. The momentum diffusion smooths the distribution function between the source particles and these energetic particles.

Results

The simulations that have been done are preliminary to a full scientific investigation of the plausibility of the diffusion coefficient used, and the predictions associated with the new code.

The addition of the momentum diffusion term in the code has led to the following conclusions.

- The momentum diffusion is a potential way the discontinuity in the simulation could be smoothed.
- The momentum diffusion coefficient must be within the range or 10^{-8}-10^{-12} (cm / s^2) to be a significant and physical effect.
- The momentum diffusion modifies the power laws observed in the tails of the distribution. This affect may be essential to obtaining a better understanding of the acceleration of energetic seed particles.

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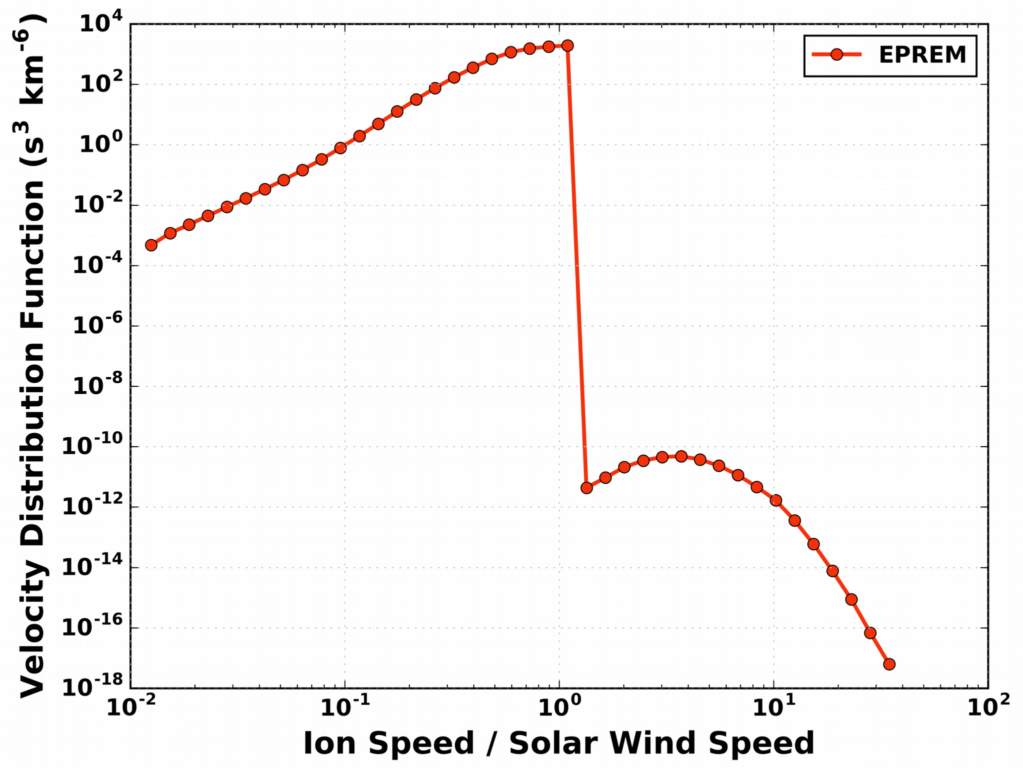
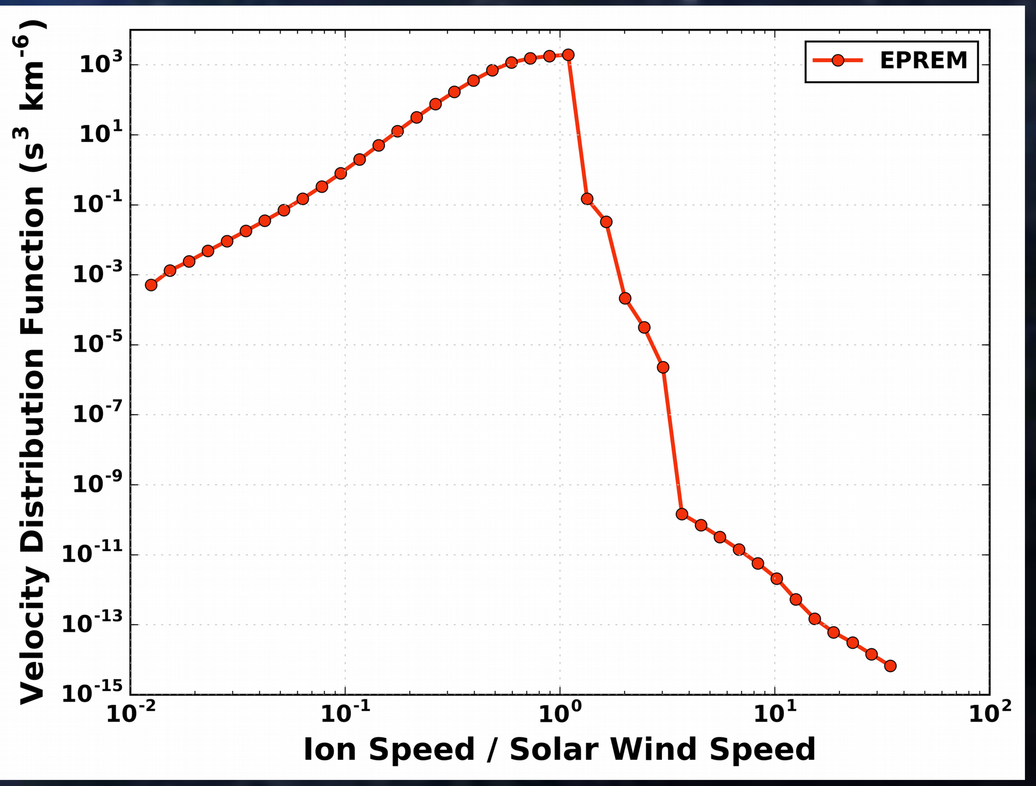
Simulated Distributions





The simulated distribution function with a CIR before (left) and after (right) adding the momentum diffusion term (with alpha=2.5):

Future Work

The momentum diffusion incorporated into the code could be used and tuned to investigate the momentum diffusion coefficient. This work would look to describe observed spectra at 1AU by using measurements from PSP and propagating those particles through the heliosphere.

With the continual improvement of the EPREM model we can hope to have high accuracy space weather predictions and we look to solve some of the remaining questions about energetic particle acceleration and transport. This will be greatly aided with the observations from Parker Solar Probe.

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References

1. Schwadron, N. A., et al. (2010), Earth-Moon-Mars Radiation Environment Module framework. Space Weather, 8, S00E02, doi:10.1029/2009SW000523.
2. J. R. Jokipii and Martin A. Lee 2010 ApJ 713 475.

Images from: eos.unh.edu and nasa.gov