Reconnection Simulations of Impulsive Flare Events in the presence of Helium-3 and Helium-4

Anna Fitzmaurice, James Drake, and Marc Swisdak

Department of Physics, University of Maryland College Park

BACKGROUND

Helium-3 abundance enhancements in impulsive SEP events have been observed since the 1970s, yet their cause remains unknown. Fisk (1978) and Temerin and Roth (1992) have both suggested that helium-3 could be preferentially heated during reconnection due to its unique gyrofrequency. In the presence of helium-4, ion cyclotron waves can be excited between 0.5-1 times the proton gyrofrequency. This would cause significant acceleration of any helium-3 as it is the only species in the corona with a gyrofrequency in this range.

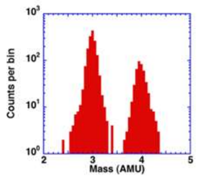

Figure 1. Helium-3 and helium-4 abundances for an impulsive event on March 21, 1999. For reference, normal $^3He/^4He$ ratio for the solar wind is ~10^{-4}. (Mason et al. 2002)

This project seeks to simulate reconnection under coronal conditions in order to observe whether the necessary instabilities occur to support this theory.

P3D SIMULATION

Reconnection simulations were done using the particle-in-cell code p3d (Zeiler et al., 2002). The code is self-consistent for all three particle species: electrons, protons, and alphas.

Initial parameters were set to coronal values:

- $\beta = 0.1$
- Helium-4 number density = 5%
- Guide field to reconnecting field ratio = 0.5
- $c / v_A = 15$*
- $m_e / m_i = 1/25$*

*The speed of light and electron to ion mass ratio used are both non-physical values to make the simulation less computationally expensive.

The size of the simulation was 102.4 x 51.2, in units of the ion inertial length, and it is periodic in both dimensions. Analysis was performed on the top left reconnection outflow, which is outlined in black in Figure 2 below.

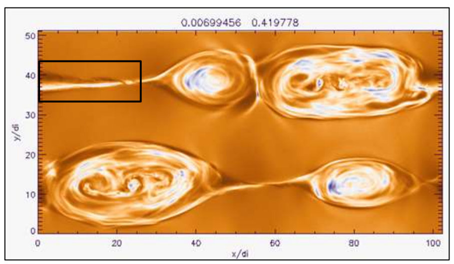

Figure 2. Helium-4 charge density normalized to the background at t = 156 ω_{ci}^{-1}. Min and max values printed at the top of the plot with color table going from orange (low) to high (high).

ABSTRACT

Observations of impulsive solar energetic particle events occasionally show enhancements of helium-3 up to ~10^4 greater than coronal abundances. Fisk (1978) and Temerin and Roth (1992) proposed that these enhancements could be caused by ion cyclotron waves and that helium-3 would be preferentially heated due to its unique cyclotron frequency. In order to test this theory, we have run kinetic simulations of magnetic reconnection in the corona using the particle-in-cell code p3d. Initial parameters were set to coronal values: 5% helium-4 number density, β equal to 0.1, and the guide field equal to 0.5 times the reconnecting field. Initial results showed instabilities develop along the separatrices of the reconnection outflows, though temperature anisotropies associated with ion cyclotron waves were not present. Fourier transforms in time of the parallel electric field at multiple locations along the separatrices showed frequencies between 1.2 and 1.6 times the proton cyclotron frequency. A second simulation with the same parameters including helium-3 as test particles is being performed to investigate the effects on helium-3.

TEMPERATURE ANISOTROPIES

While the helium-4 showed significantly more heating than the protons and instabilities are clearly present along the bottom and top separatrices, the temperature anisotropy typically associated with ion cyclotron waves, $T_{perp} > T_{par}$, is true for only a small region along the center of the current sheet.

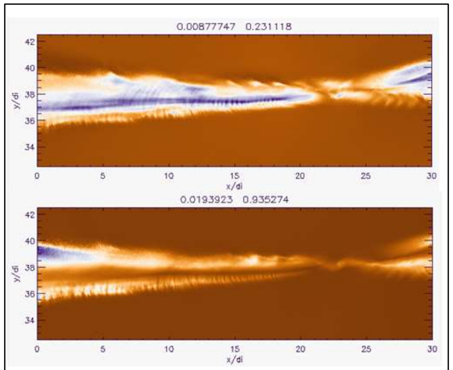

Figure 3a. Helium-4 perpendicular temperature (top) and parallel temperature (bottom). Min and max values printed at the top of each plot with color table going from orange (low) to blue (high).

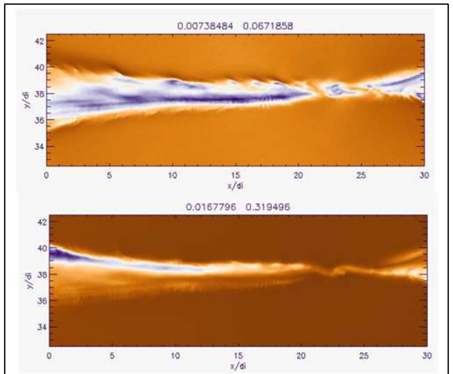

Figure 3b. Protons perpendicular temperature (top) and parallel temperature (bottom). Min and max values printed at the top of each plot with color table going from orange (low) to blue (high).

ELECTRIC FIELD FFTs

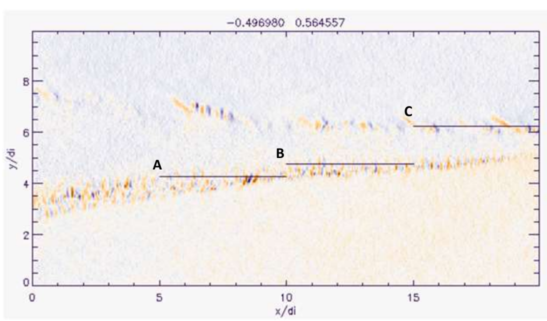

Figure 4. Parallel electric field at t = 141 ω_{ci}^{-1}. Black lines denote the locations where FFTs were taken. Min and max values printed at the top of the plot with color table going from orange (negative) to blue (positive).

Fast Fourier transforms in time were performed on the parallel electric field at two locations along the bottom separatrix and one location along the top separatrix (see Figure 4, left). Data was output every 0.1 ω_{ci}^{-1} for a total of 150 time slices.

In order to reduce noise, an FFT was taken at every point along a horizontal line and then averaged over the approximately 100 grid points.

FFT output is shown in Figure 5 (upper right of poster). The two FTTs along the lower separatrix both peak around 1.67 ω_{ci} while the FFT on the upper separatrix peaks around 1.2 ω_{ci}. As there were no clear peaks at the helium-3 gyrofrequency, it is unclear whether this instability could sufficiently heat the helium-3.

FFTs (continued)

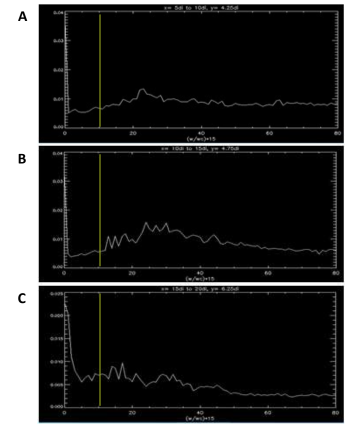

Figure 5. The FFTs taken at each of the locations labeled in Figure 4: A and B corresponding to the lower separatrix and C corresponding to the upper separatrix. Units on the horizontal axis are (ω/ω_{ci})*15, i.e. 1 ω_{ci} = 15. The yellow vertical lines represent the helium-3 gyrofrequency.

ADDING HELIUM-3

Based on results so far, it is unclear how helium-3 will be affected by this system; therefore the next stage of the project involves adding helium-3 to the simulations as test particles, i.e. the system will be able to act on the helium-3 without it affecting the system. Simulation parameters will be kept exactly the same as before. Velocity distribution functions will be analyzed to determine any acceleration of the helium-3.

CONCLUSIONS

This project is currently ongoing. However, we have already seen that under coronal conditions with helium-4 as 5% of the total number density, instabilities can be produced along the separatrices of reconnection outflows. It is unclear how helium-3 will be affected by these instabilities, therefore further simulations are being run which include helium-3 as test particles.

REFERENCES

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