Combining Hydrodynamics Modeling with Test Particle Tracking to Improve Flare Simulations

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I. Abstract

We are combining thermal plasma and non-thermal particle numerical models in order to improve flare simulations. Non-thermal particle collision models provide heating and momentum deposition for the thermal plasma. The thermal plasma models in turn provide an evolving temperature and density structure for the non-thermal particles' target plasma. This allows us to simulate thermal and non-thermal flare emission under a variety of increasingly realistic solar conditions. The model flare emission is then folded through the response functions of solar observatories in order to provide simulated data that can be compared to observational results. This provides a means to verify the predictions of multiple flare models with observed flare behavior.

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II. Method

Beams of non-thermal particles, with an anisotropic pitch angle profile, are injected into the loop apex. The Particle Transport Code (PaTC) tracks non-thermal test particles as they propagate through the model plasma. Energy and pitch angle cosine ($\theta=\cos^{-1}[v_{parallel}/v_{total}]$) changes due to collisional interactions with protons and electrons and magnetic effects are modeled for each test particle. The change in energy and momentum of each test particle is multiplied by a scaling factor and used as an input to the hydrodynamic equation solver, MSULoop. MSULoop then calculates the plasma's response to the input of energy and momentum and provides the temperature and density structure of the plasma, which is used as target inputs to the next iteration of PaTC.

Initial Loop Properties

Loop Length:	4.4×10^9 cm	$Temp_{loop\ top}$:	1.4×10^6 K
$B_{foot\ point}$:	100 G	$B_{loop\ top}$:	37 G
$Density_{foot\ point}$:	2×10^{13} cm^{-3}	$Density_{loop\ top}$:	1×10^9 cm^{-3}

Exponentially decreasing magnetic field

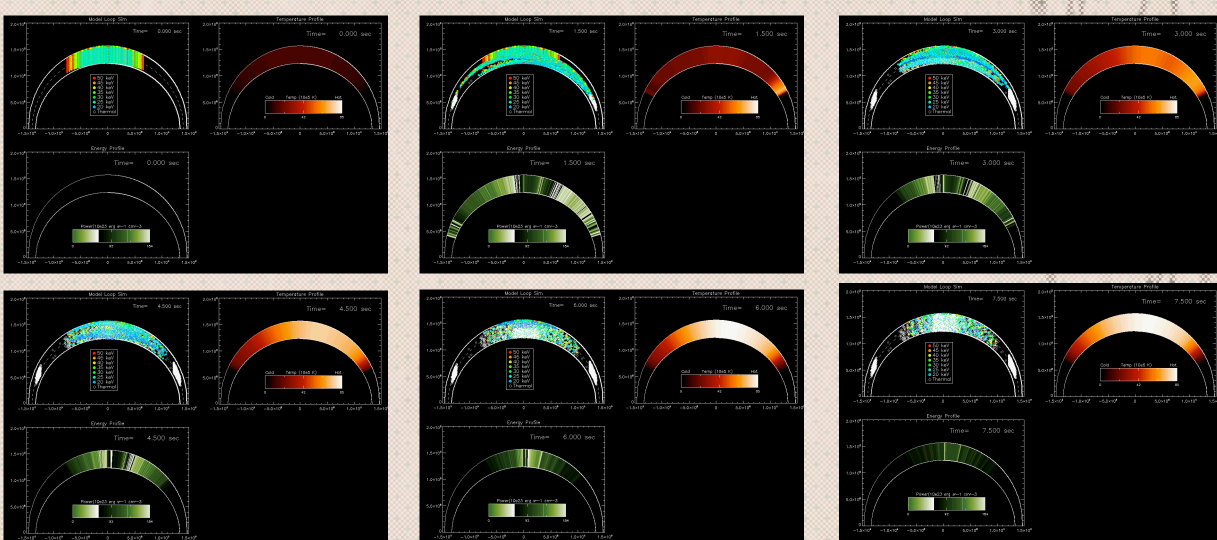
Total Simulation time is 30 seconds

Non-Thermal Particle Properties

Total Energy Deposited into Loop:	10^{28} ergs (Small Flare)
Non-Thermal Power Spectrum:	$F(E)=F_0E^{-3}$, where F_0 is a constant
Non-Thermal Particle Energy Range:	25-50 keV
Beam Duration:	2 seconds

Simulation reports:

Still images of the loop evolution. Each frame shows the track of non-thermal particles, temperature profile, energy deposition, and density profile. Please come and talk to me about viewing the entire simulation movie.



III. Conclusions

There is a strong initial deposition of energy at the foot points followed by a long period of energy deposition at the loop top. This is a result of non-thermal electrons in the loss cone precipitating quickly to the denser chromosphere where they are immediately thermalized and give all of their energy to the plasma in the loop.

The longer period of energy deposition at the loop top at first seems counter-intuitive since the plasma density is much lower. However, non-thermal particles can deposit a significant amount of energy at the top of converging magnetic loops. The effect of magnetic mirroring causes the non-thermal particles to spend a significant fraction of their time at the loop top causing more collisions at this point than would be expected in the non-mirroring case. This result helps to provide an explanation for loop top hard X-ray sources observed in some flares.

In future, the density and temperature profiles will be used to generate spectra that will be folded through various instrument response functions, such as XRT on Solar-B, in order to directly compare theoretical models and observation. We will also calculate hard X-ray emission in order to compare with instruments such as HXT and RHESSI.