

Modeling a full coronal loop observed with Hinode/EIS and SDO/AIA



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ABSTRACT

Physical parameters measured from an observation of a coronal loop from Gupta et al. (2015) using Hinode/EIS and SDO/AIA were used as input for the hydrodynamic, impulsively heated NRLSOFM 1-d loop model. The model was run at eight different energy inputs and used the measured quantities of temperature (0.73 MK), density ($10^{8.5} \text{ cm}^{-3}$) and minimum loop lifetime to evaluate the success of the model at recreating the observations. The loop was measured by us to have an un-projected length of 236 Mm and was assumed to be almost perpendicular to the solar surface (tilt of 3.5 degrees) and have a dipolar geometry.

Our results show that two of our simulation runs (with input energies of 0.01 and 0.02 $\text{ergs cm}^{-3} \text{ s}^{-1}$) closely match the temperature/density combination exhibited by the loop observation. However, our simulated loops only remain in the temperature sensitive region of the Mg 278.4 Å filter for 500 and 800 seconds respectively which is less than the 1200 seconds that the loop is observed for with EIS in order to make the temperature/density measurements over the loop's entire length. This leads us to conclude that impulsive heating of a single loop is not complex enough to explain this observation. Additional steady heating or a collection of additional strands along the line-of-sight would help to align the simulation with the observation.

INTRODUCTION

A complete understanding of coronal loop heating can only be achieved when simulations and observations are used together effectively. A crucial function of observers is to accurately measure loop parameters (e.g., temperature, density, loop length, magnetic field strength, plasma flows etc.) and use this analysis to infer the processes at work within the loop. This allows modelers the opportunity to contribute to the analysis of the loop by uncovering what initial conditions and heating parameters are needed to make sense of the observations. Progress in understanding coronal loops could take place at a faster rate if this type of cooperation was more commonplace.

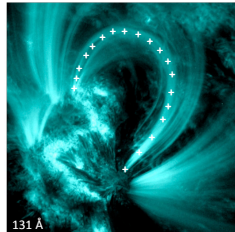


Figure 1 — SDO/AIA 131 Å image of AR 11131 on 11 December 2010. The loop examined by Gupta et al. is traced out with + symbols.

A recent publication by Gupta et al. (2015) observed a loop with Hinode/EIS and SDO/AIA and set out to do just this. They measured multiple parameters of the loop and listed their results clearly with the view that simulators would benefit from their work. They looked at AR 11131 (Figure 1) and measured temperature, density, filling factor and diameter along the length of the entire loop.

Gupta et al. (2015) is a refreshing attempt to encourage simulators to work on this loop and we have set out to answer whether or not we can recreate their observation using our impulsively heated loop model. This will allow us to comment on the likely source and magnitude of the heating taking place and see if our loop parameters match up with their observations.

SIMULATED LOOP

The model used in this analysis is the hydrodynamic code named the Naval Research Laboratory's Solar Flux Tube Model (Mariska et al. 1982, NRLSOLFTM). This NRL code allows a number of parameters to be explored and takes in values of loop length, heating rate, heating duration, loop inclination, abundances etc.

We found the observed loop's geometry was best fit by a dipolar structure with a length of 236 Mm and a small inclination of 3.5 degrees. The NRL model is relatively quick to run (~5 mins for a loop of this length) so we performed eight runs of the simulation with a range of different initial energy inputs. These energies were chosen to give the simulated loops a temperature evolution that falls within a realistic range i.e., loops with equilibrium temperatures of $2\text{MK} \leq T \leq 7\text{MK}$ (Figure 2, left panel). Here, we define the equilibrium temperature as the temperature at which the majority of the cooling is achieved by radiation rather than conduction (see Winebarger & Warren 2004).

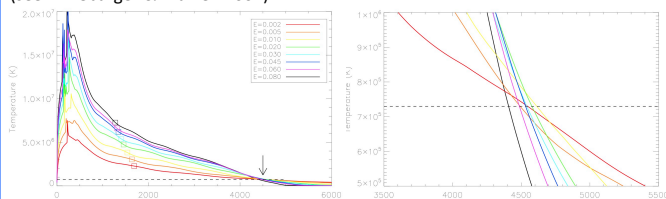


Figure 2 — Left: Full temperature evolution of eight runs of the simulation. The dotted line indicates the average temperature of the observed loop and the arrow shows the point where the simulations cross this line. The square symbols indicate the equilibrium temperature of each simulation. Right: Zoomed in area of this crossing point.

RESULTS

Gupta et al. (2015) suggest at the time of observation, the loop was nearly isothermal along its length and width with an average temperature of 0.73 MK. This temperature is indicated in Figure 2 left panel by the horizontal dashed line and the point at which the simulations reach this point is highlighted by an arrow. The right panel of Figure 2 shows a close up of this region and shows that simulations of different input energies pass through this region with different slopes - higher energy simulations have steeper slopes as they cool faster.

The next step was to compute the density of each simulation at the time the temperature was at the observed value of 0.73 MK. Figure 3 shows the comparison between these density values and the input energy of the simulation. Higher energy inputs result in higher densities in the simulated loops due to an increase in the amount of material evaporated into the loop from the chromosphere. The two dashed lines in Figure 3 show the minimum observed density (apex) and the average density in the top 50% of the loop as shown in Gupta et al. (2015). Our Figure 3 shows that two of our simulations lie in this region.

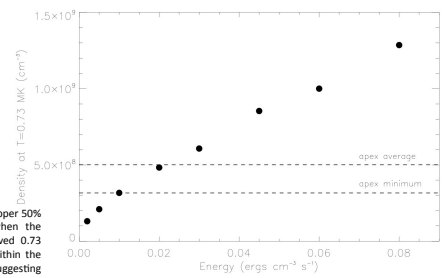


Figure 3: Density values (based on average of upper 50% of loop) of each simulation at the time when the simulation's temperature matched the observed 0.73 MK. Two of the simulations have a density within the limits of the observation at this temperature suggesting the NRL model can produce observations with the same temp/dens profile.

LOOP LIFETIME

Another observation our simulation has to explain is the lifetime of the loop observed at specific temperatures. Using their figure of the loop as observed with Hinode/EIS (sized at 110" across), given the step size of 3" and the exposure time of 35s, we estimate this loop took 20 minutes to raster over. This is the minimum time their loop was observed in Mg VII 278.4 Å. Figure 4 shows the contribution function of Mg VII 278.4 Å plotted using the CHIANTI (v7.1) function *gotnt* with a constant density of $10^{8.5} \text{ cm}^{-3}$. We have defined two temperatures (T1 and T2) where the full-width at half-maximum (FWHM). These temperatures define when the plasma should be observable in this line.

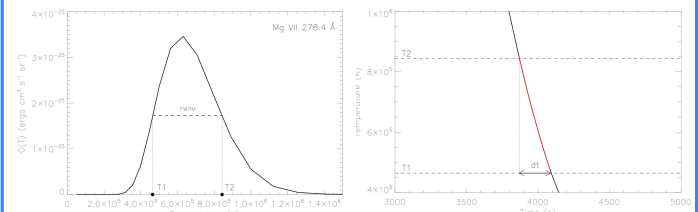


Figure 4 — Left: Plot of the contribution function of Mg VII 278.4 Å with the full width half maximum (FWHM) point indicated. The temperatures at this point are highlighted by the vertical dashed lines and labeled as T1 and T2. Right: Example plot of the temperature evolution of one of the simulations. The temperature region at which Mg VII is activated is marked with horizontal dashed lines (T1 and T2), and the time the simulation spends in this region is marked as dt.

DISCUSSION

We measure the time it takes each simulation to cool from T2 to T1 as shown in Figure 5. This time (dt) is then plotted against the input energy of each simulation. A clear trend is seen where lower energy simulations spend an increased amount of time going from T2 to T1 (as was indicated in Figure 2, right panel). The dashed line on Figure 5 shows the minimum time of 20 minutes that the observation spent in this temperature region.

Although the 3rd and 4th simulations had a similar temperature/density combination as the observation they disagree on this timescale and would not be observable in Mg VII 278.4 Å for the same length of time as the observed loop.

Our results show that our impulsively heated 1d loop model can be used to match the temperature and density of the observed loop but that the cooling periods do not match. Therefore, we conclude that simple impulsive heating cannot explain this observation and either additional steady heating component, or modeling the loop as multiple strands could bring simulation and observation closer together.

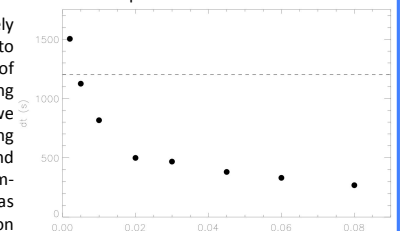


Figure 5 — Plot showing the eight simulations result of dt versus input energy. dt is the time each simulation spends at the temperature Mg VII is sensitive to.

References:
 Gupta, G. R., Tripathi, D., & Mason, H. E. 2015, *ApJ*, 800, L40
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