Investigation of the Necessary Conditions for Hot Chromospheric Solar Flare Regions

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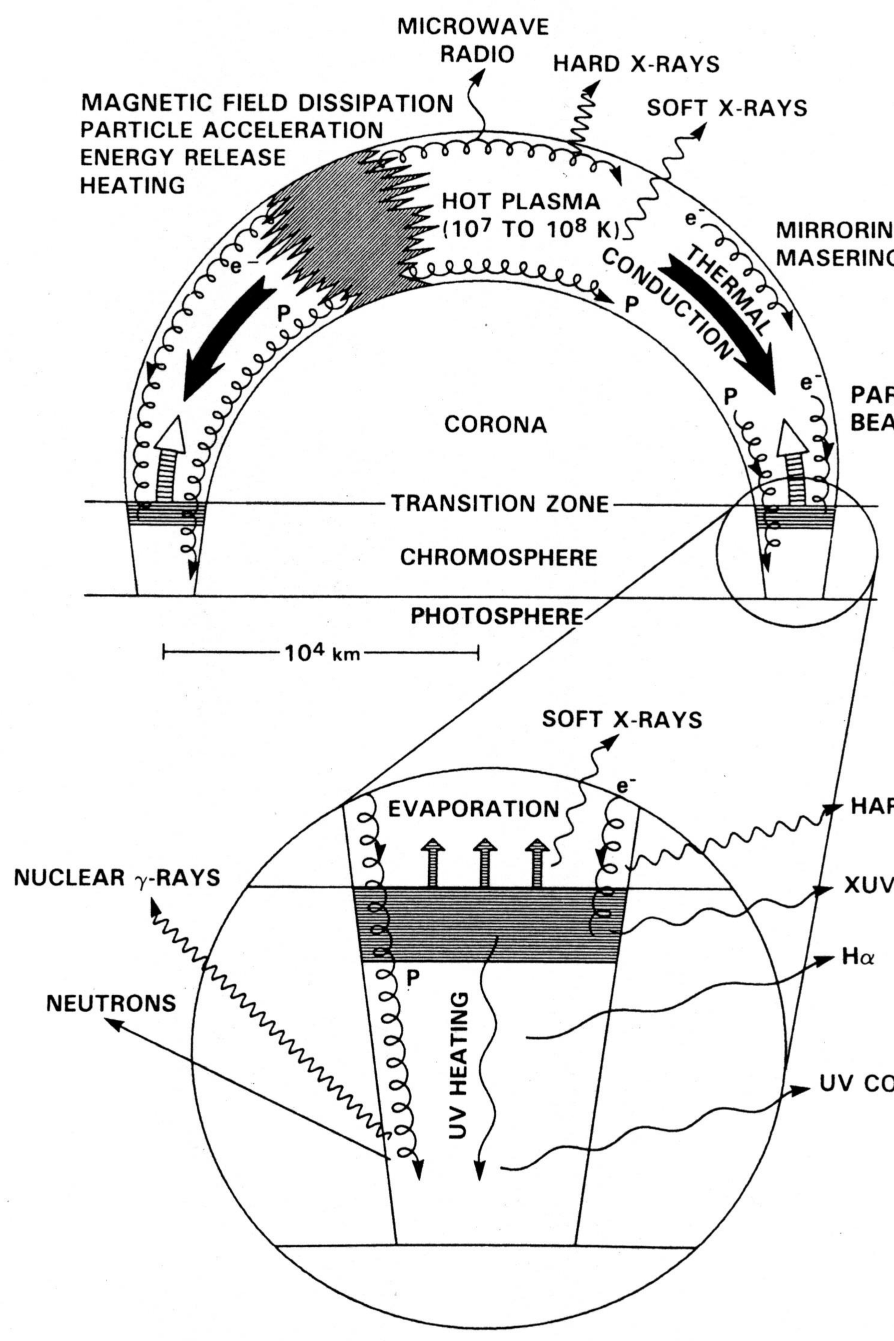
1 – Introduction

Solar flares are intense bursts of radiation that occur in active solar regions. Energy is stored in tubes of "active" plasma formed by the looping magnetic field of the corona (outer solar atmosphere). When this energy is released it propagates through the plasma, heating it, accelerating particles and emitting large amounts of radiation across the entire spectrum. Much of the energy is deposited in the chromosphere (lower, dense atmosphere), impulsively heating the local plasma, sending shocks both up and down the tube, leading to a complex hydrodynamic evolution and emission of radiation.

Solar flares manifest two distinct phases, impulsive (where the main energy release occurs) and gradual (as the plasma evolves)[1]. The flare energy transport mechanism is still a question of much debate[2,3]. The prevailing model is electron beams, and hard X-ray observations indicate the presence of large numbers of electrons at the flare footpoints, but this may pose problems with electron density in the tenuous corona[2].

(a): Diagram of a small flaring loop, indicating the major regions and emission processes at work.



Gurman, J. B, "NASA's Solar Maximum Mission: A look at a new Sun" (NASA publication, June 1987)

2 – Motivation

Recent observations have shown the presence of compact regions with chromospheric densities and coronal temperatures[4,5]. Current models have been unable to reproduce these flare sources. **This project investigates the physical conditions required to produce these hot footpoints and simulates the spectra of such events.** These synthetic spectra are finally compared to observations from EVE data for a "typical flaring event".

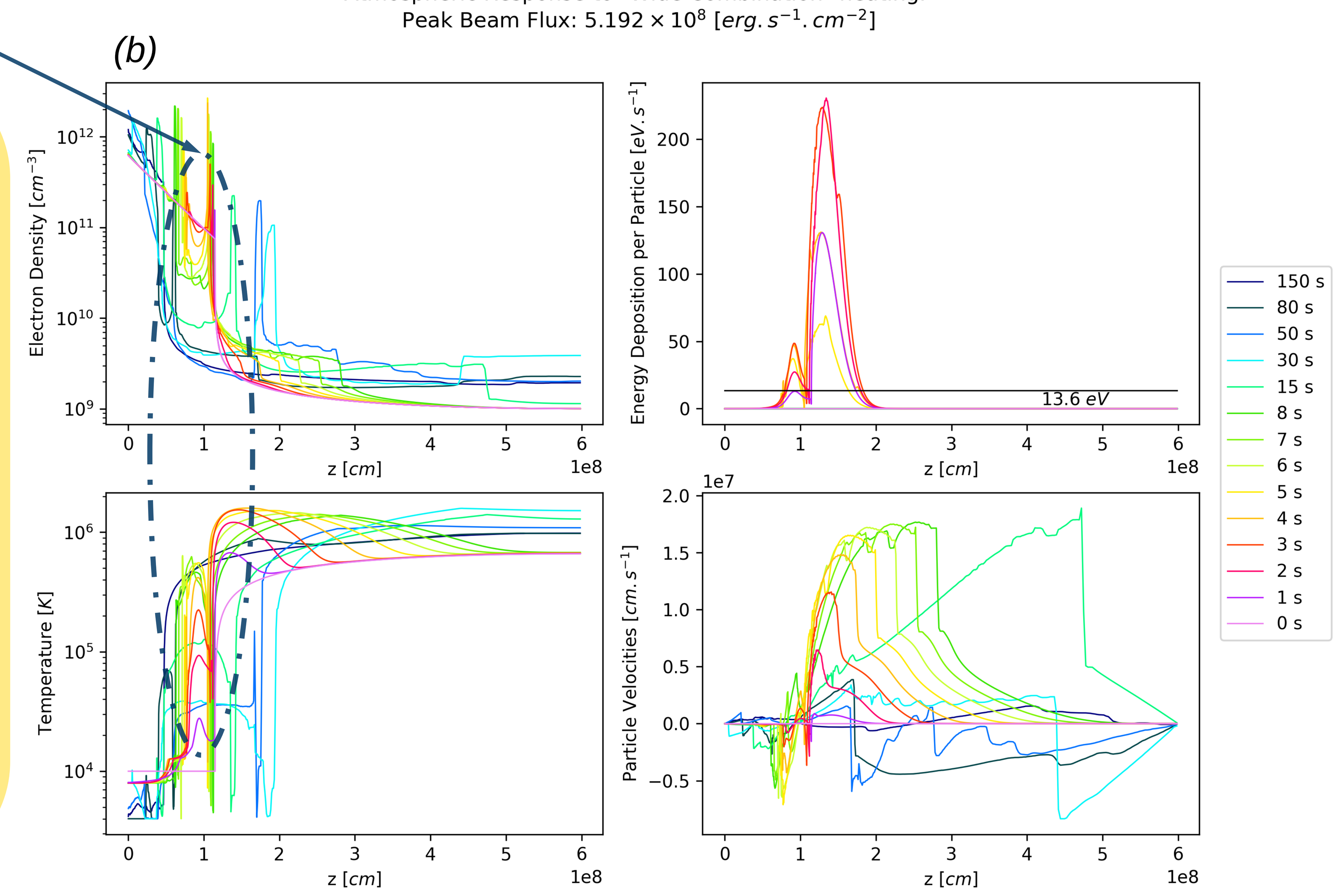
Our investigation centres on a 1D radiation-hydrodynamic code based on a model by J. Mariska[6,7] and rewritten by the author. This is combined with the CHIANTI[8,9] spectral line database (and associated tools) for the production of synthetic spectra. To investigate heating free from the bias of current energy transport models we use ad hoc heating and observe the hydrodynamic evolution of the flux tube.

3 – Methodology

We have developed a 1D radiation-hydrodynamic simulation tool based on Mariska's model[6,7], using a combination of C++ and Lua. Initially a simple stable atmosphere is formed, then energy is deposited over a period of time. The hydrodynamic code computes the radiative losses[10] and evolves the plasma. The result is shown in *(b).* This raw simulation data is used to calculate input data for the CHIANTI[8,9] spectral line database tools, in the form of a differential emission measure[11] (DEM) and grid of average density per binned temperature. These are produced by using a *local gradient reconstruction* method to handle the scale of the shocks produced by this impulsive heating. **CHIANTI tools are then used to compute the line emission from Fe VIII, X, XII, and XIII formed at different temperatures (see *Table 1*) at different time snapshots** (these lines were chosen from Milligan & Dennis (2009)[12] as they emit strongly at the temperatures diagnosed). **Finally light curves are plotted from these snapshots.**

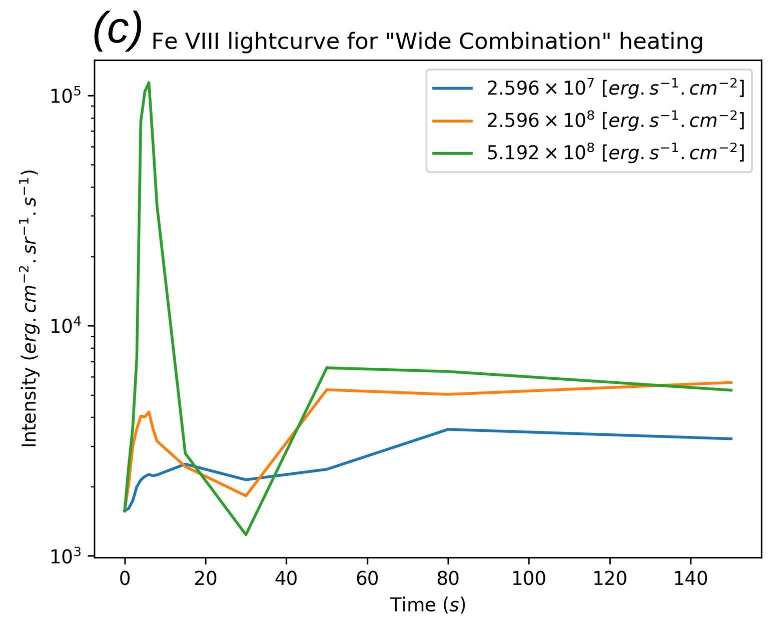
Creating Hot Footpoints

Our ad hoc heating function deposits energy (in the form of pressure) over a Gaussian region. The "Wide Combination" heating is the superposition of two Gaussians: a wide Gaussian centered in the transition region representing 60% of the total beam flux (FWHM: 600 km) and a narrow Gaussian at the top of the chromosphere representing the remaining 40% (FWHM: 120 km). The heating function intensity is modulated over 6 s. **This heating method produces an approximate hot slab.** Such heating could possibly be explained by impact of an electron beam on the dense chromosphere and dissipation of Alfvén waves in the transition region.



4 – Results

The light curves from the above simulation are shown in *(c)*, *(d)*, *(e)* and *(f)*. For the stronger heating regimes we see two phases, a short impulsive phase and a more gradual hydrodynamically evolving phase. These results can be qualitatively compared with EVE data *(g)*; whilst the others decay slowly – like the data – the Fe VIII line rapidly dips to below its initial value. This can probably be explained by the nature of the 1D simulation, and the lack of surrounding chromospheric plasma to heat and then emit.



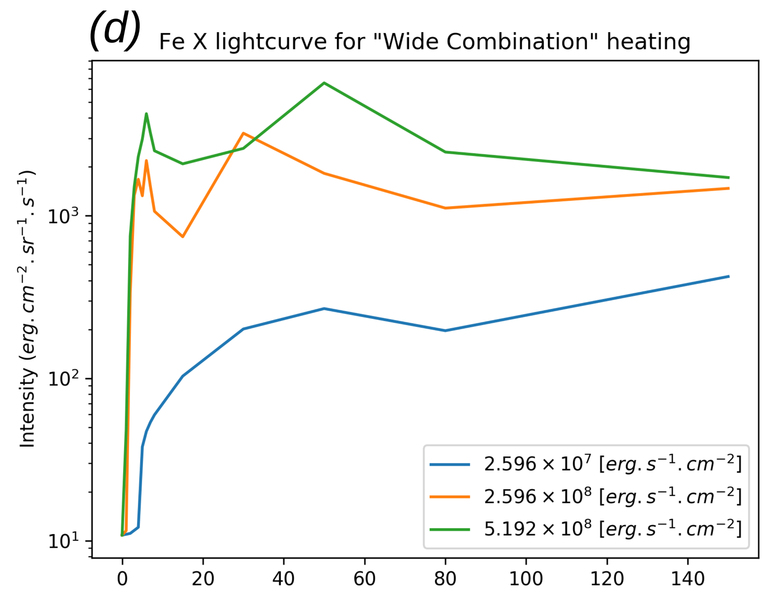
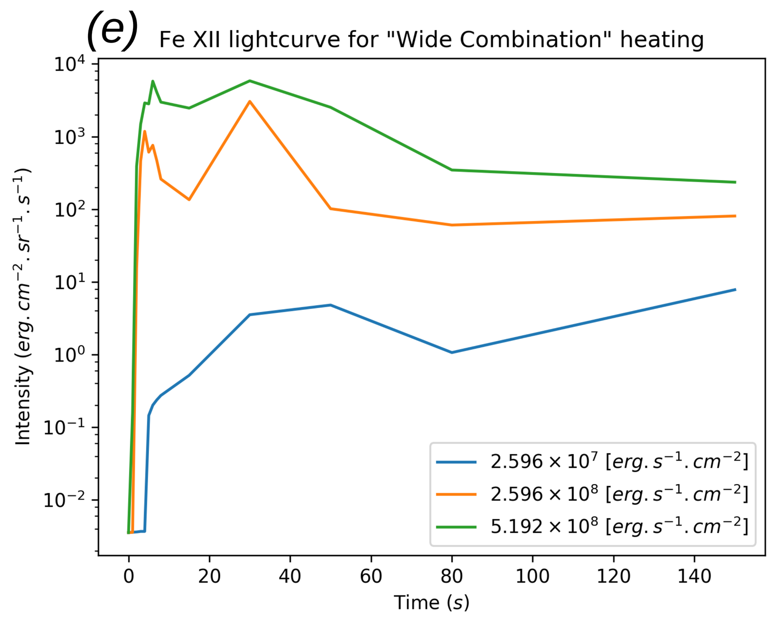
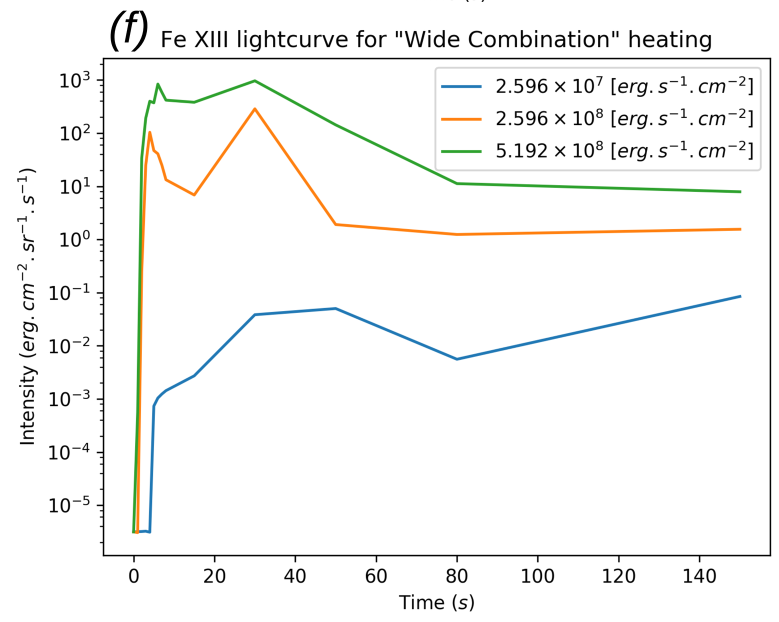
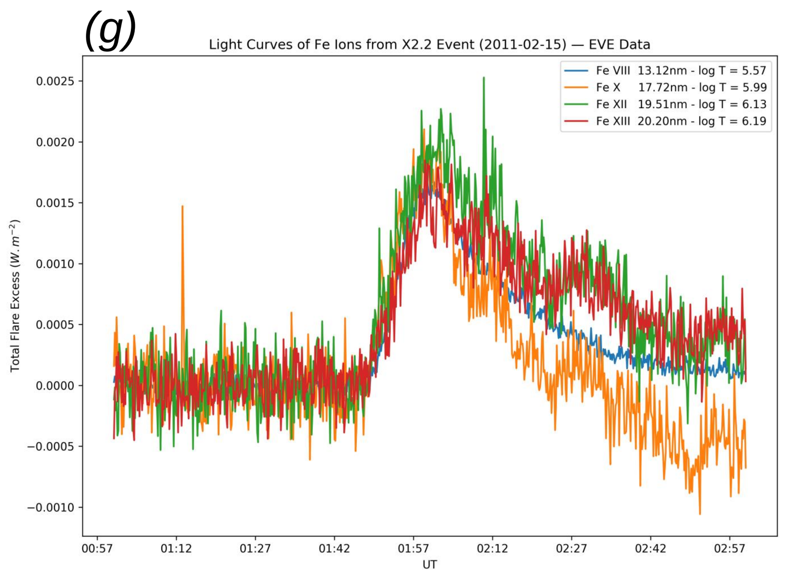


Table 1: Peak Line Temperatures

Line	Peak Temperature (MK)
Fe VIII	0.6
Fe X	1
Fe XII	1.25
Fe XIII	1.5







5 – Conclusion

We have shown that **a simple radiation-hydrodynamic model can produce transient hot, compact chromospheric flare sources.** The energy required for this is well within the flaring budget, provided it is deposited in the correct location. This model could be improved by the addition of optically thick radiation losses as used in RADYN[13]. The use of ad hoc heating functions has allowed us to determine the feasibility of reproducing these atmospheres, without being constrained by a particular energy transport model. There is still much future work to be carried out in this area, using more elaborate models to attempt to physically create these hot sources.

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