COMBINING SIMULATIONS OF RADIATIVE HYDRODYNAMICS AND PARTICLE ACCELERATION TO MODEL SOLAR FLARES

Fátima Rubio da Costa [1], Vahe' Petrosian [1], Wei Liu [1], Mats Carlsson [2]
(1): Stanford University; (2): Institute of Theoretical Astrophysics, University of Oslo

We present a numerical study combining a modified version of the "RADYN" radiative hydrodynamic code (Carlsson & Stein, 1992) with the "FLARE" code (Petrosian & Liu, 2004). While "RADYN" describes the atmospheric response to a beam of non-thermal electrons (Allred et al., 2005), "FLARE" models the acceleration and transport of particles and the radiation of a solar flare in non-local thermodynamical equilibrium (non-LTE).

INTRODUCTION

Our aim is to improve the calculations of hydrodynamic response of the solar atmosphere to an energy input by accelerated particles. To archive this, we merge "RADYN" with "FLARE" and combine radiative hydrodynamic simulations of a flaring atmosphere with the modeling of particle acceleration.

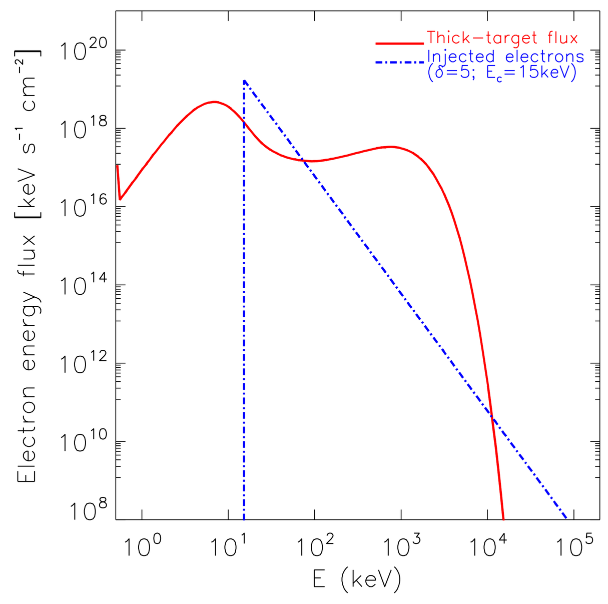
- The "**RADYN**" radiative hydrodynamic code:
  - Solves the 1-D radiative hydrodynamic equations.
  - Analyzes the energy transport by a beam of non-thermal electrons, injected at the top of a 1D coronal loop.

- The "**FLARE**" particle acceleration code:
  - Includes stochastic acceleration and electron transport, including pitch angle scatter and energy loss.
  - Computes the collisional heating rate and bremsstrahlung emission along the loop.

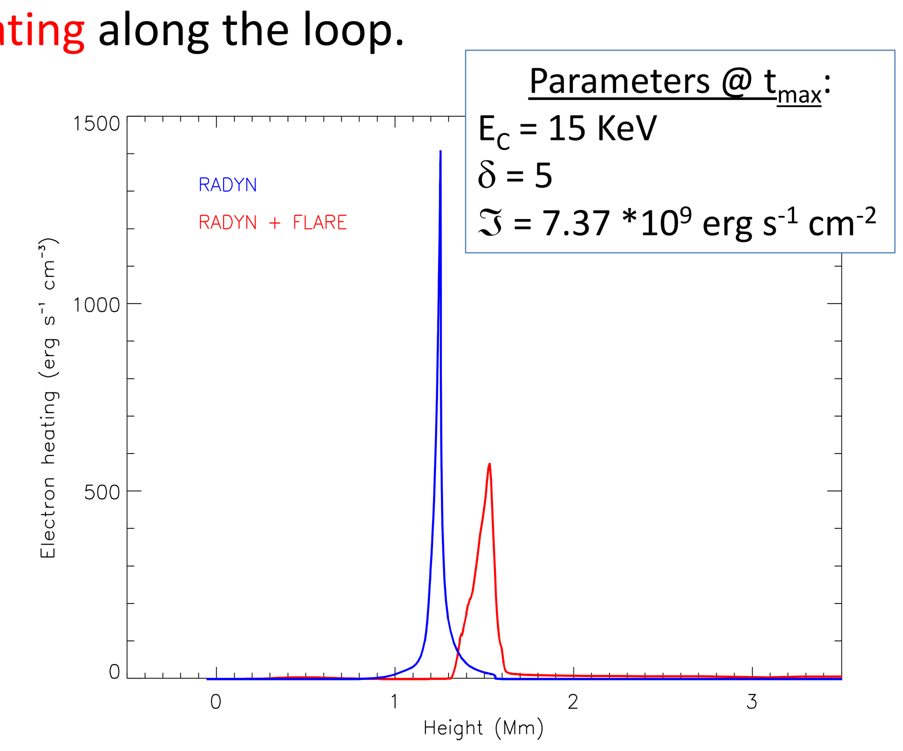
The results include a radiative calculation of several atoms, achieving advancements over the results from Liu et al. (2009).

METHOD

Using the atmospheric conditions of "RADYN", the injected non-thermal energy is calculated by "FLARE" every **0.005** seconds.



Comparison of the **electron flux spectra** of the injected electrons at the top of the loop and the one due to the evaluated transport and heating along the loop.

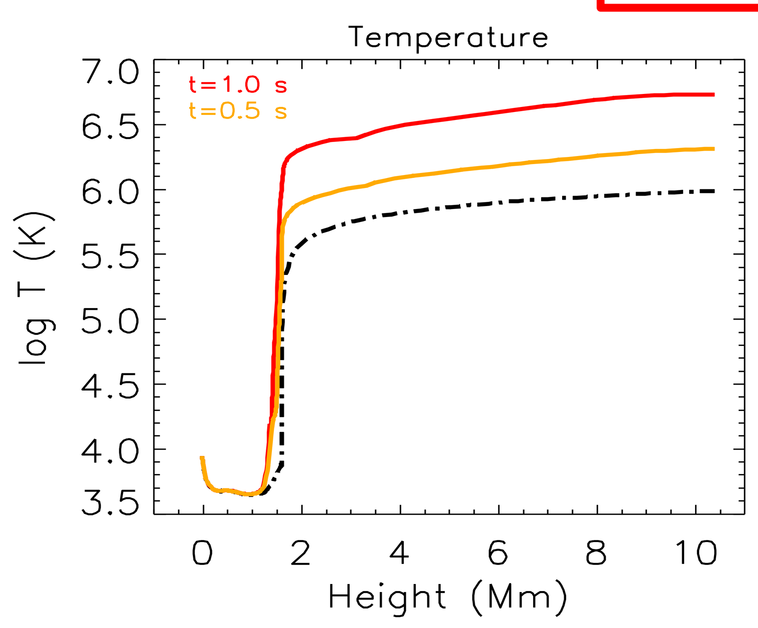


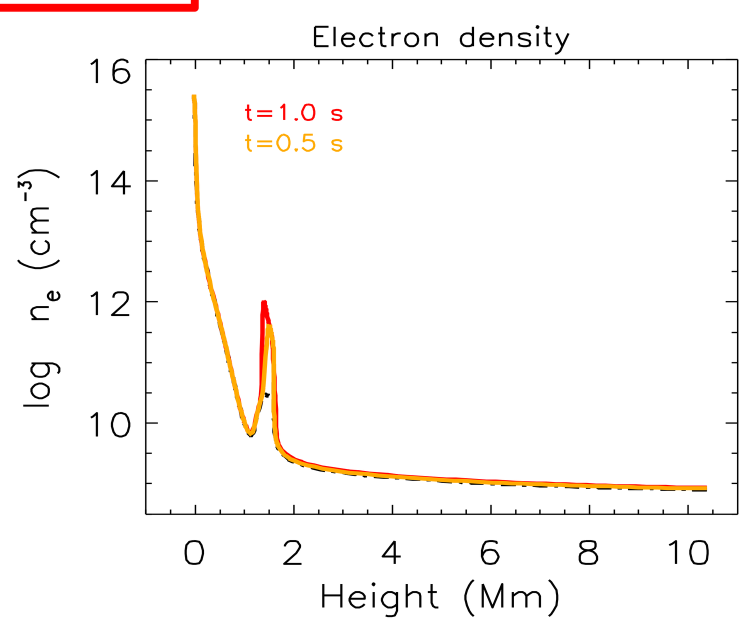
The flux of injected electrons follows a dynamic evolution with a triangular shape, having its peak at 1 second. The electron flux spectra is normalized at t_{max}.

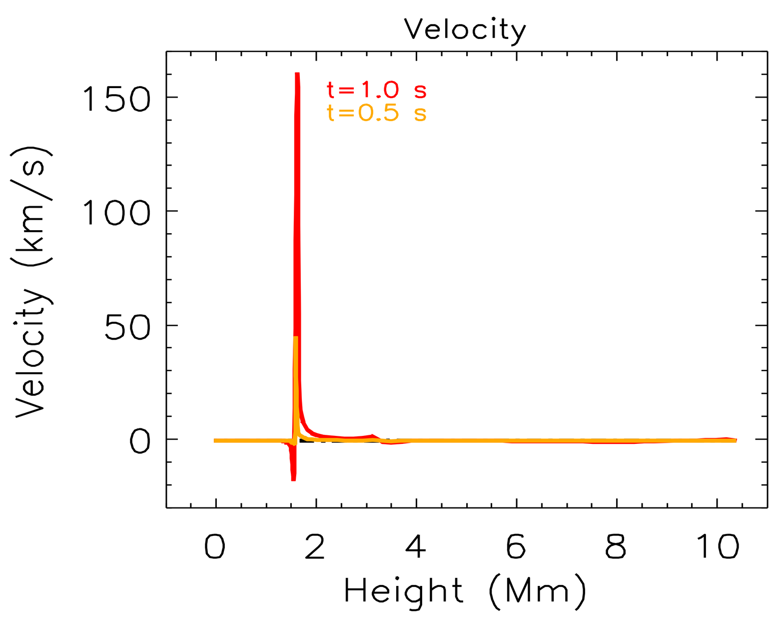
EVOLUTION OF THE ATMOSPHERE

To determine how much the transport and acceleration calculations affect the atmosphere, we compare the results of both simulations:

RADYN + FLARE

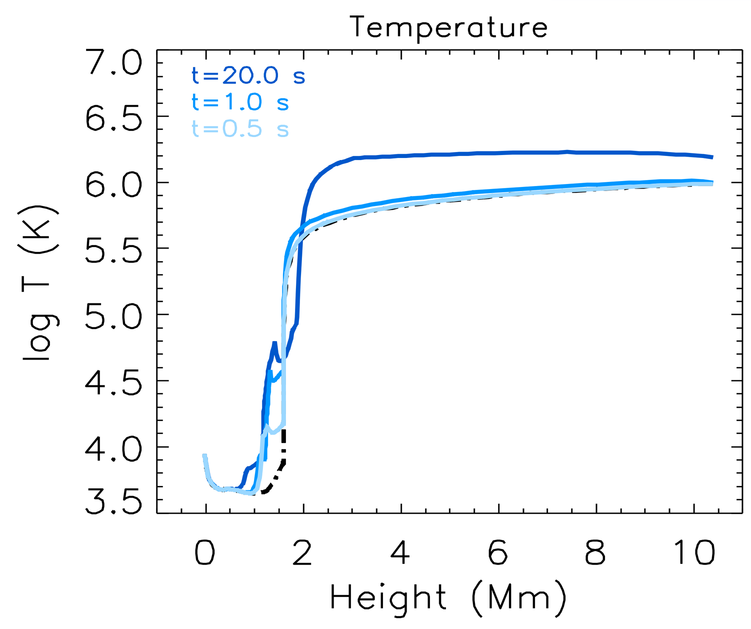


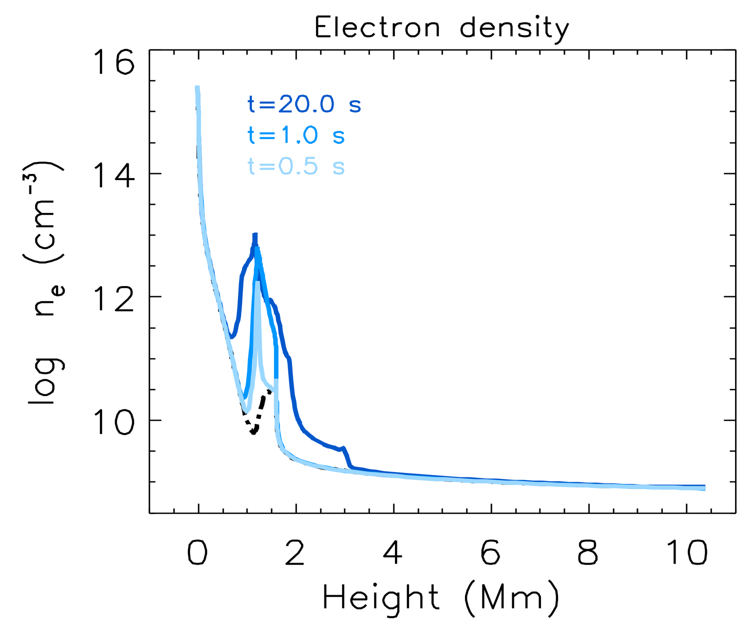


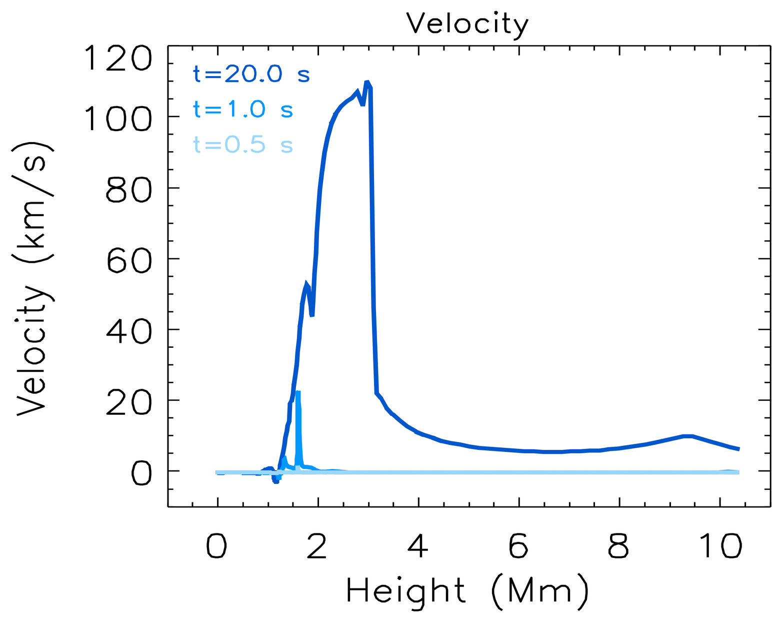


The densities of the plasma and electrons are almost not affected by the heating.
The velocity shows strong upflows, concentrated mainly at 1.5 Mm → there is no evidence of chromospheric evaporation .
The heating moves quickly to the corona.

RADYN + POWER LAW



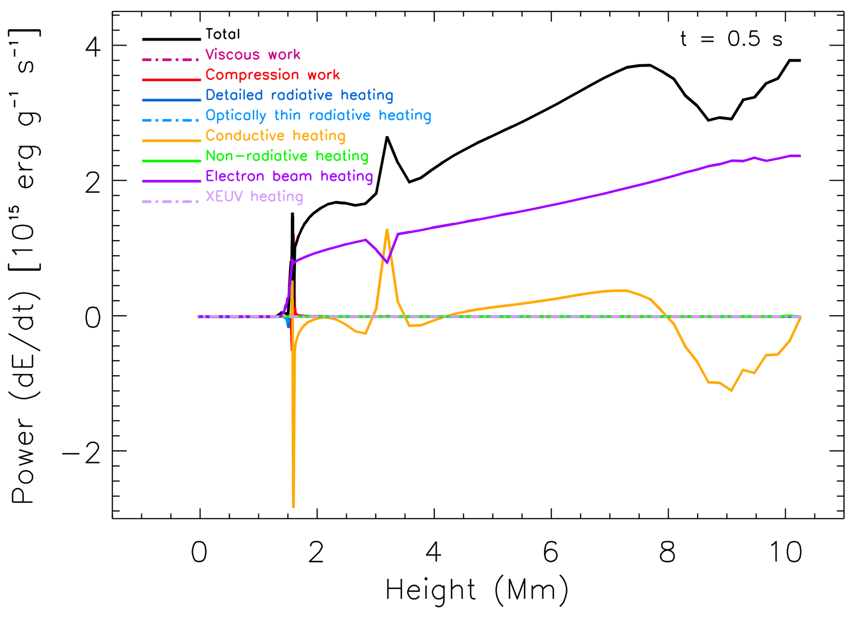




The injected beam of electrons pushes the plasma upwards, moving the transition region to upper layers.
The velocity is much smaller at initial states and its peak moves towards the corona, showing indices of chromospheric evaporation.
The heating is concentrated mainly in the chromosphere.

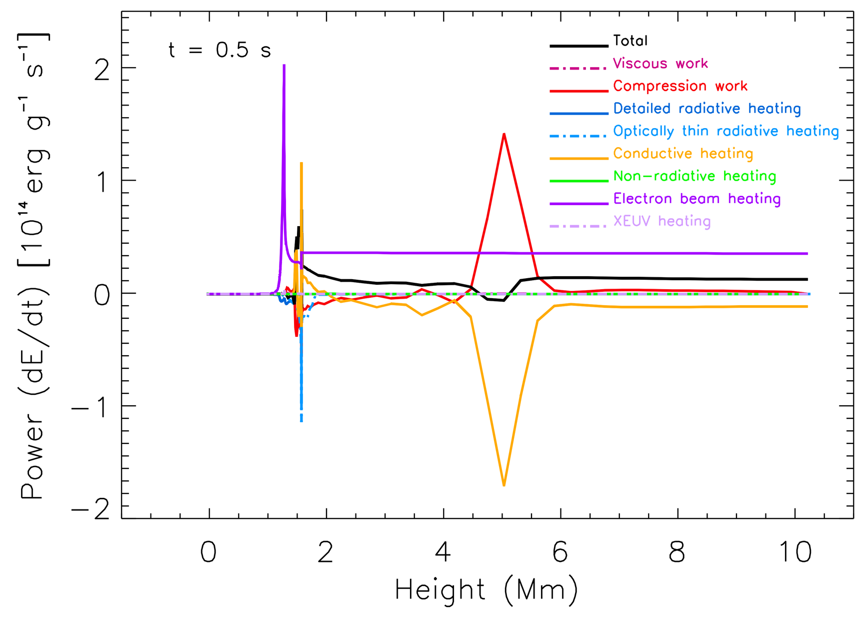
ENERGY CONTRIBUTIONS

The rate of change of the **total internal energy** is divided into seven different heating terms: viscous heating, compression work, radiative heating (detailed: solid; thin: dashed), conductive heating, non-radiative heating, non-thermal electrons heating and x-ray heating (dashed).



The conductive heating moves quickly to the corona, explaining the fast chromospheric evaporation.
The non-thermal electron energy rapidly spreads to the upper layers.

The non-thermal electrons heat the atmosphere at the height where the non-thermal electrons are deposited. The conductive power is balanced by the radiative heating power.



The remaining terms have a minor contribution to the total power.

CONCLUSIONS & FURTHER WORK

- The combination of the injection of electrons at the top of the loop, together with the evaluation of the energy deposition along the loop heats the corona is short times, almost not changing the density of the plasma. The motion of the plasma is localized near the transition region. As result, the atmosphere shows a fast and strong heating at the corona.
- Upcoming chromospheric observations of flares to be conducted with the high resolution IRIS imaging spectrograph will provide an excellent data set for this study. They will allow us to compare numerically modeled and observed emissions of solar flares in several lines using more robust simulations than possible before.