The EUV Late Phase of Solar Flares: Long-lasting Cooling or Additional Heating?

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Abstract: **The EUV late phase of solar flares is a secondary emission enhancement (mainly in Fe XVI 33.5 nm) separated from the primary flare event by tens of minutes to hours. It has been clear that the late EUV emission comes from the higher but related flare loops, rather than the flare core region. By far there are two major explanations for the EUV late phase: one is additional lower heating, and the other is long-lasting cooling signature. We study these two phenomena through some experiments using the EBTEL model. Our results show that the EUV late phase can appear with only cooling process existing in two sets of flare loops with quite different lengths. The additional heating is just a sufficient but not a necessary condition for the EUV late phase.**

Introduction

- The EUV late phase of solar flares is proposed from SDO/EVE observations.
- Four criteria for EUV late phase (defined in Woods et al. 2011):
  (1) a second peak of the warm coronal emissions (Fe XV and Fe XVI) several minutes to a few hours after the GOES soft X-ray peak;
  (2) no significant (< 10%) enhancements of the hot emissions (SXR and Fe XX/XXIII) during this second peak;
  (3) an eruptive event as seen in images (CME/dimming);
  (4) a second set of longer loops that are higher than the original flaring loops and at a much later time than the first set of post-flare loops
- Explanations for the EUV late phase:
  It originates from a much larger and higher loop system;
  a) Long-lasting cooling; b) additional heating

The EBTEL model

- The EBTEL (*enthalpy-based thermal evolution of loops*) model is a zero-dimensional, high efficient model.
- It computes the mean temperature (T) and density (n) of coronal plasmas by solving time-dependent energy and momentum equations:

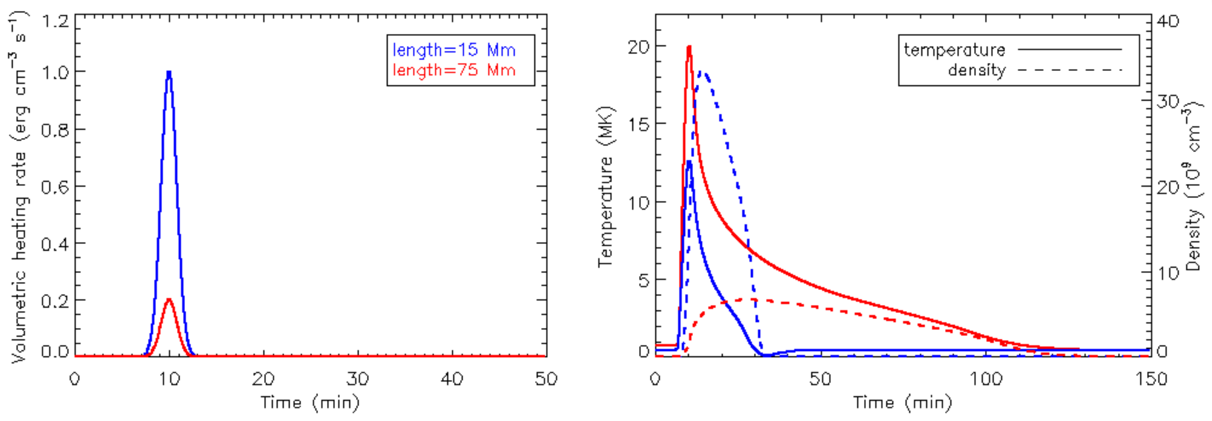
$$\frac{dn}{dt} = -\frac{2c_2}{5k_B T}\left[\frac{F_c}{L} + c_1 n^2 \Lambda(T)\right]$$

$$\frac{dp}{dt} = \frac{2}{3}[Q(t) - (1+c_1)n^2\Lambda(T)],$$

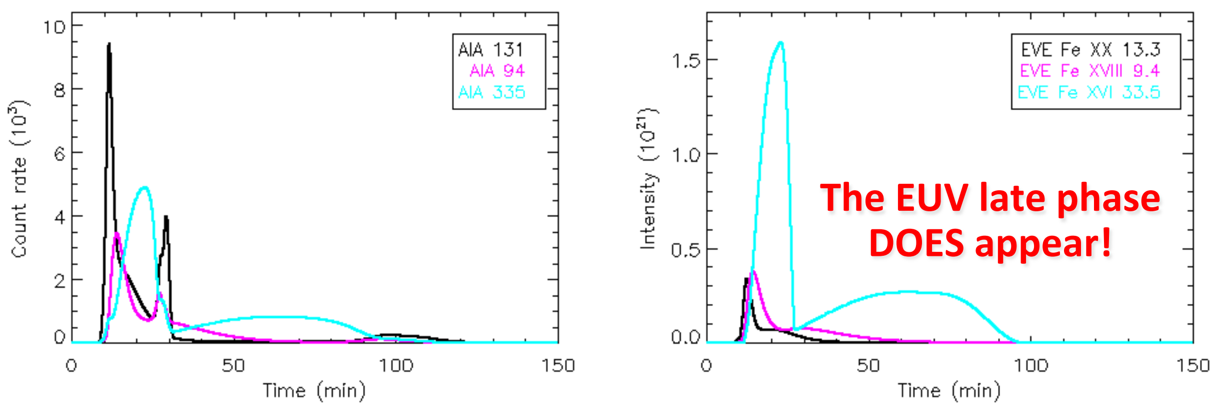
- Inputs: heating profile Q(t), loop length (L);
  Outputs: T, n, v, P
- Using the T and n, we can calculate the synthetic AIA and EVE emissions.

Experiments

- Case 1. main heating of two (sets) flare loops with length ratio 5.

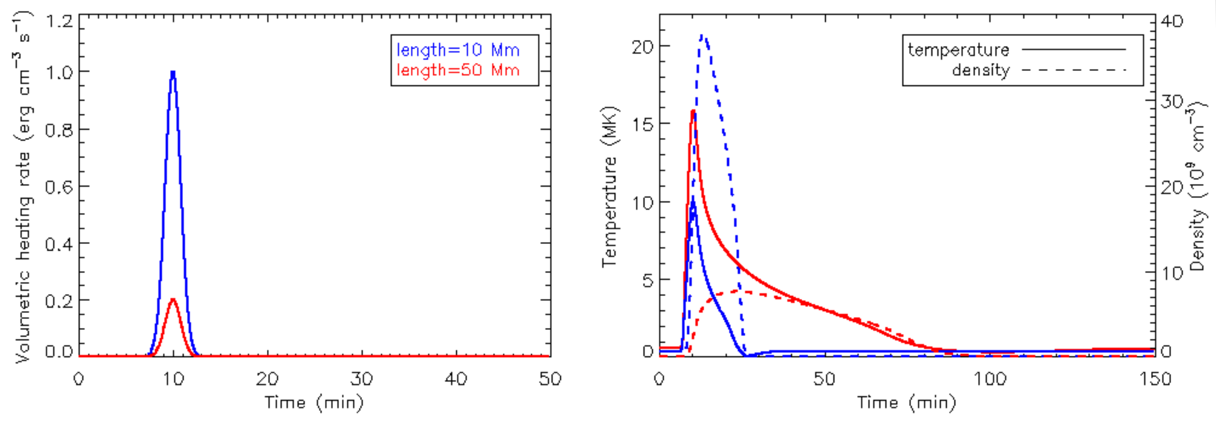


Left: Heating profiles of the two loops whose length ratio is 5. They have the same total energy added at the same time.
Right: Temperature and density evolution of these two loops.

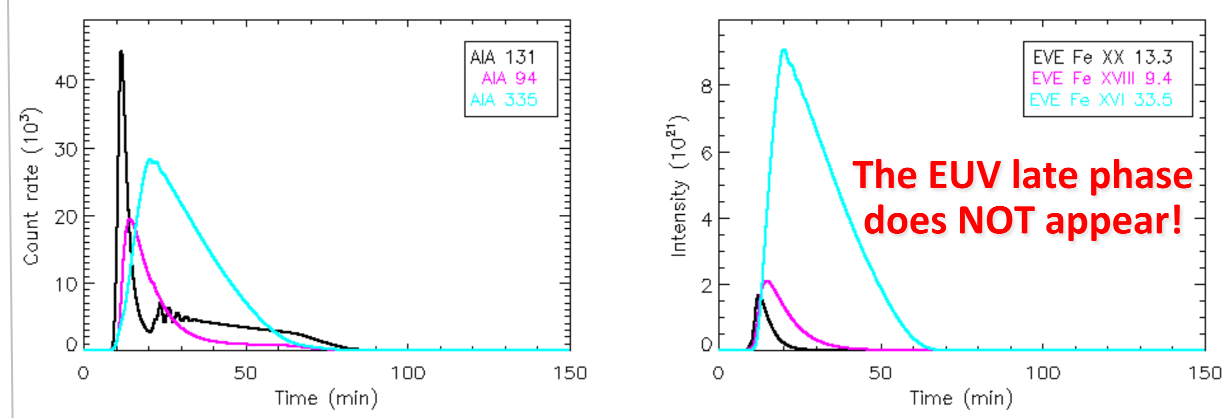


Left: Synthetic fluxes (total of these two loops) in the three high temperature channels of AIA. *Right*: Synthetic intensities (total of these two loops) in three high temperature lines of EVE.

- Case 2. main heating of a series of (21) flare loops with continuous lengths.

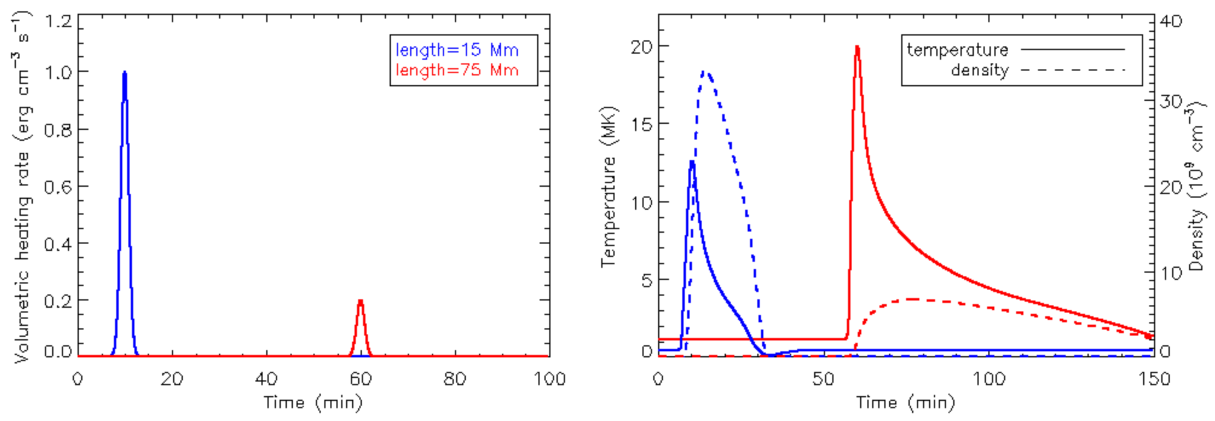


Left: Heating profiles of the shortest (10 Mm) and longest (50 Mm) loops. All these 21 loops have the same total energy added at the same time.
Right: Temperature and density evolution of the shortest and longest loops.

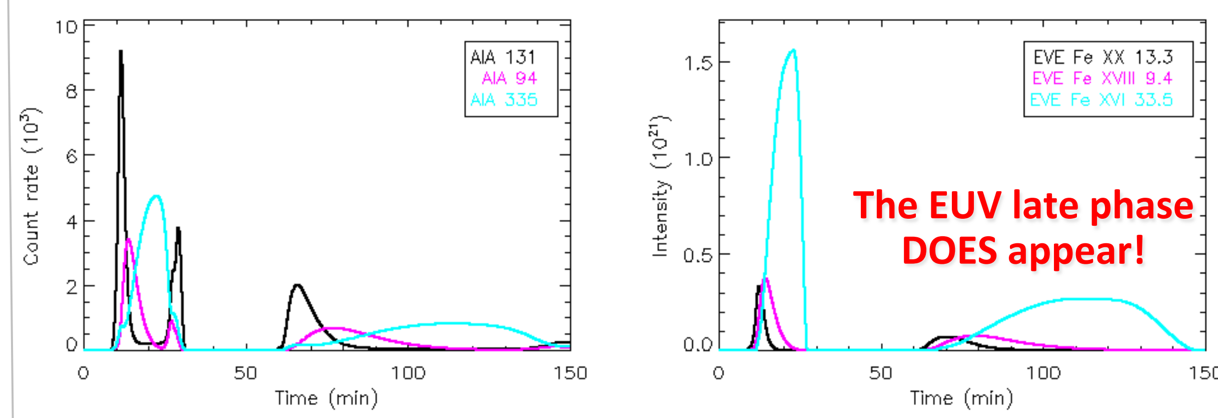


Left: Synthetic fluxes (total of these 21 loops) in the three high temperature channels of AIA. *Right*: Synthetic intensities (total of these 21 loops) in three high temperature lines of EVE.

- Case 3. main + late(additional) heating of two (sets) loops with length ratio 5.



Left: Heating profiles of the two loops whose length ratio is 5. They have the same total energy but added at different times.
Right: Temperature and density evolution of these two loops.



Left: Synthetic fluxes (total of these two loops) in the three high temperature channels of AIA. *Right*: Synthetic intensities (total of these two loops) in three high temperature lines of EVE.

Conclusions:

(1) The EUV late phase can appear with only cooling existing in two sets of flare loops with quite different lengths.
(2) The additional heating is just a sufficient but not a necessary condition for the EUV late of solar flares.

References:

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