SUMER OBSERVATIONS OF HEATING AND COOLING OF CORONAL LOOPS

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ABSTRACT

Hot-loop transient events observed by SUMER in hot EUV lines are known to trigger loop oscillations, as reported by Kliem [1] and Wang et al. [2], [3]. Apart from the inference of physical parameters in the solar corona, these observations also carry the signatures of heating and cooling of coronal loops. We present the light curves for various highly-ionized ions which were simultaneously observed during and after the trigger. Even though the majority of SUMER events occurs on subflare level, it is clear that the heating is impulsive and drives the plasma to a very high temperature of up to 10 MK within minutes. During the cooling phase, however, we find the plasma in gradually decreasing ionization stages which implies that the entire loop system involved in such events is basically in the isothermal state. Such events may also help in our understanding of mass supply and energy transport in the corona.

1. INTRODUCTION

During the recent flare campaigns SUMER has observed a large number of hot loop oscillation events. In addition to the oscillatory behaviour, these events reveal also a more general aspect of coronal loops and will hereafter be referred to as hot loop transient events (HLTE). Here, we will focus on one remarkable side aspect, namely the heating and cooling of the emitting plasma involved in such events. We will only discuss short-lived, but often recurring transient HLTEs. Following Dennis [4] we do not discuss long during, persisting events without Doppler flows which seem to belong to another category of hot emission.

2. OBSERVATIONS

In this communication we will present three typical examples of HLTEs, observed on 16 Apr 2002, 8 May 2001, and 26 Sep 2000. In all cases presented, a tiny volume of very cool plasma flashes up, a behaviour, which has some similarities with explosive events as noted by Wang et al. [2]. The first case is a double event seen at two spatial locations along the slit, which are marked in Fig. 1. Interestingly, the cool plasma flashes, which coincide with the start of the oscillations are some pixels displaced from the location of the oscillating hot loops. A similar observation was reported by Kliem [1]. The trigger seems to emanate from one of the foot points of the loop system as seen from context images of the EIT imager. There is evidence that inflowing material pushes the plasma confined in

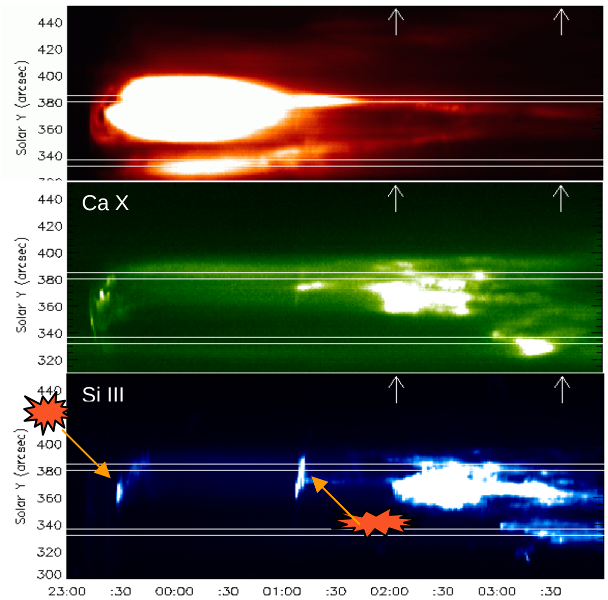

Fig.1: x-t plot of a recurring hot-loop transient event (HLTE), observed in Fe XIX 1118 Å (6.7 MK), Ca X 1116 Å /2 (0.7 MK), and Si III 1113 Å (0.03 MK). The formation temperatures are given in brackets. The positions of both HLTE starting points are indicated.

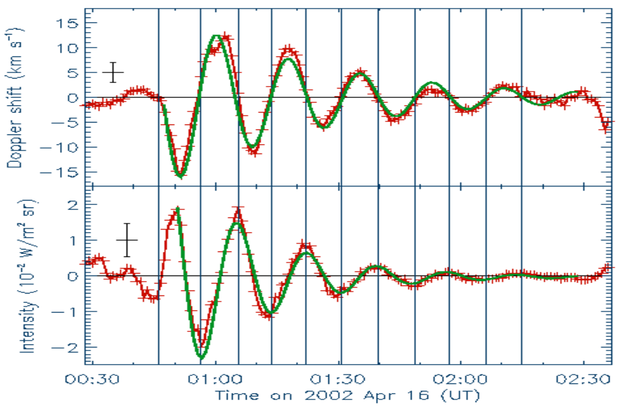

Fig. 2: Doppler. shift and spectral radiance of the Fe XIX emission in the lower band of Fig. 1 (second trigger).

the loop, which then travels along the loop until it is reflected at the other foot point, thus introducing a standing wave. The oscillation is best seen as line-of-sight Dopplershift, while the radiance oscillation is often obscured by a strong background trend (cf., Fig. 1). The oscillation is strongly damped, so that only 2 to 5 periods can be observed. The oscillation is seen in velocity and after removing the strong background trend - with 1/4 period phase delay - in intensity. Our observations support a model, where this initial trigger excites the first axial compressional eigenmode. The argumentation for slow-mode standing compressional waves has been given by Wang et al. [2].

It is evident from Fig.1 that the timing of the light curves of different species shows delays. This feature will be investigated in more detail in the other examp-les presented here. Fig.2 displays an event which was observed on 8 May 2001 in Fe XIX, Fe XVII, Ca XIII, and Ca X and is another example for recurrance of HLTEs. A volume of 40000 km in diameter is impulsively triggered by a heating event, which drives the plasma temperature of the loop system up to 7 MK within a few minutes, and excites a spatially coherent oscillation. After 60 minutes a second event is observed. Both events are co-spatial with no lateral movement and both events start with a redshifted emission.

This observation shows that the loop, which has has been hit by a HLTE is unchanged and still in place, when the second trigger comes. It seems to be a common feature that multiple HLTE always start in the same direction, which implies that it is always the same footpoint that generates the trigger.

In Fig.2, the phase shift of the emission in various spectral lines in even more obvious. We have integrated the counts of the affected pixels along the slit for all spectral lines analyzed in this example. The light-curves are displayed in Fig.3. Around 14:40 the Fe XIX emission starts to rise and peaks 20 minutes later. During the fall-off phase the second trigger occurs. The same behaviour is seen in the Fe XVII light curve, however with a delay of more than 30 minutes and with a more smooth appearance. The light curve of Ca XIII starts on a high level, but falls off by more than a factor of two, when the first trigger arrives. A similar but smaller drop is generated by the second trigger. Finally, the light curve rises again and peaks more than 60 minutes later relative to Fe XVII. Ca X is a typical and common coronal species, which seems to have contributions from all along the line of sight. Therefor only little impact seems to come from the HLTE triggers. However, almost 60 minutes after the Ca XIII peak also the light curve of Ca X rises and reaches a significant peak.

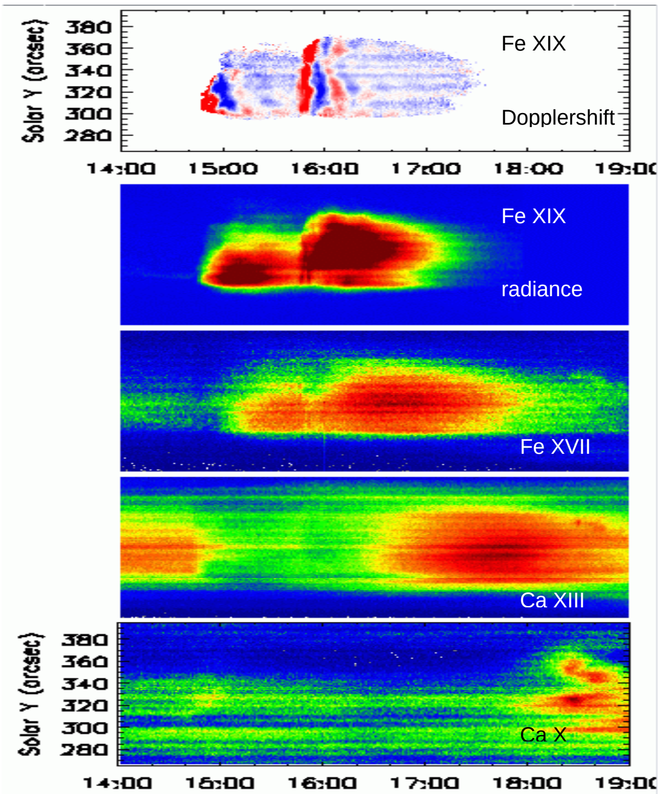

Fig.2: Another recurring event observed in Fe XIX 1118 Å (6.7 MK, both flow and spectral radiance), Fe XVII 1154 Å (2.9 MK), Ca XIII 1133 Å (2.0 MK), and Ca X 1116 Å /2 (0.7 MK) shows the typical HLTE temporal evolution.

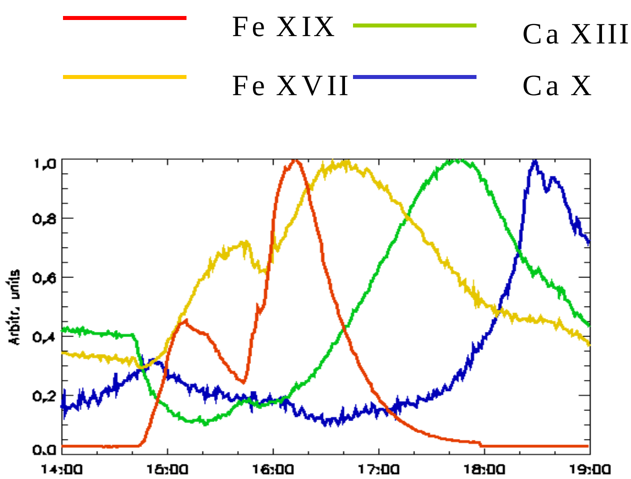

Fig. 3: Light curves (spectral radiance integrated along the slit) have been calculated for the event shown in Figure 2. At 14:40 UTC the Fe XIX emission starts to rise, while dimming occurs in Ca XIII, indicative of the rapid ionization during the trigger. Even the fine structure of this double event is seen with some time delay in cooler lines.

For our third example, which already has been described by Curdt et al [5] and which has been used for diagnostic purposes by Feldman [6], we have also derived the light curves. In Fig. 3 we show the relationship between maximum of the light curves and formation temperature of the ion. Again, the tempera-

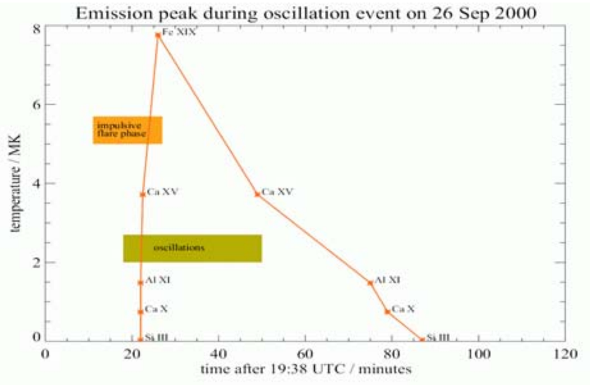

Fig. 4: For the light curve maxima of this example formation temperatures have been plotted. The peaks occur sequentially in different ionization stages. This is a clear indication that the emitting plasma is at one temperature at a given time, in contradiction to multi-thermal heating models.

ture of the loop rises to very high temperatures of 7 MK within minutes. This rise is the starting point of an oscillatory motion, which has already been damped, when the temperature of the loop system has come back to moderate values. The peak emission in cooler emission lines is delayed as a function of temperature.

3. DISCUSSION

The emission of Fe XIX is a proxy for soft X-rays. Our observations are therefor indicative for flare type process which triggers HLTEs. Although only in 40% of the cases soft X-ray peaks have been found in the light curves of the GOES full-disk X-ray monitor, which coincide with HLTEs. Obviously, HLTEs need only a small impulsive trigger, which is in many cases obscured by the X-ray flux coming from the solar disk.

We have shown that HLTEs start with an impulsive trigger which drives the temperature in the coronal loop up to 7 MK. The energy input seems to last only for a few minutes until the Fe XIX light curve reaches its maximum indicative for the end of the impulsive phase of the microflare. It is well known that that for most flares, the soft X-ray emission measure is roughly proportional to the time-integrated hard X-ray intensity [7]. These arguments led to the thick-target model of Brown [8].

The fact that we normally observe an undisturbed sinusoidal oscillation clearly implies that HLTE are induced by one-and-only-one initial trigger. And the heating and cooling curve demonstrates that the plasma is at one temperature at a given time or in other words - isothermal.

While real flares actually change the magnetic configuration of coronal loop systems, this does not seem to be the case for HLTEs. They may be compared to microflares which for some reason were not able to make it, although they try repeatedly.

HLTE may not be the only mechanism for the heating of coronal loops. These arguments suggest that HLTE are the and elementary ('atomic') constituents of coronal loop heating. This conclusion does not exclude heating mechanisms based on a different mechanism.

Some models assume successive short-lived heating events in multi-thread loops during a flare, which implies that all temperatures should be observable at any time during the event. Our observations have shown that the plasma is basically isothermal while it cools down and therefor contradicts those models, unless they describe a different phenomenon.

Magnetic dipole transitions in highly ionized species, e.g. the Fe XIX 1118 Å have the same excitation process as soft X-rays and can be taken as SXR-proxy as mentioned before. They allow, however, different from data from SXR-imagers to derive high-resolution Doppler flows and are therefor a powerful tool to study the dynamics of SXR events. The YOHKOH SXR jets, which seem to be a common feature in AR loops as reported by Shibata [9], may be a similar phenomenon than HLTEs observed by SUMER.

We have noticed that the overall appearance of HLO events is remarkably similar to that of explosive events (EE) or blinkers. In particular the fact that EE often show red-blue assymmetry or time lag as well as a slanted appearance along the slit (cf., Dere [10]) (separation of red and blue component) resembles HLTE features, while the difference of the observed time constants does not seem to be a serious argument. Another hint may be the correlation of cold emission and HLO emission, which is sometimes observed [1]. This could also cast a new light on the observations of dynamical coronal events of Curdt [11] and Innes[12]. Ayres [13] denote the anlogous behaviour of stellar flare activity seen in hires STIS spectra and solar explosive events as curiosity.

SUMMARY

Hot-loop transient events (HLTE) seem to be a common feature in coronal loop systems. HLTEs often trigger slow-mode loop oscillations. Because of the strong damping the oscillations can only be observed while the plasma is at very high temperatures. This may be the reason, why they have not been observed before.

HLTEs are impulsive and often recurring flare-like events, although occurring mostly at sub-flare level.

After a sudden start, the sinusoidal oscillations are damped, but otherwise undisturbed. This fact implies that HLTEs are induced by one and only one initial trigger.

The heating and cooling curve demonstrates that the plasmas are at one temperature at a given time or in other words - isothermal, but variable in time.

The observed HLTEs seem to be a basic building block and elementary ('atomic') constituent of coronal loop heating.

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