SUMER OBSERVATIONS OF ACTIVE REGION LOOP DYNAMICS

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ABSTRACT

Active region loops on the east limb of the Sun were observed by SUMER in sit-and-stare mode for several days. Different heights of the loops crossed the spectrometer's field-of-view as the loop systems rotated onto the disk. The number of small flaring events at a height of 40 Mm is about 1 per hour and they remain hot (6 MK) for about 20-40 min. This flaring activity is rarely seen in lines formed at 5 MK or below. In Ca XIII (4 MK) the events show up as a subtle intensity decrease followed by a small intensity increase as the plasma cools. Many events exhibit periodic Doppler shifts in Fe XIX lines. Co-incident *Yohkoh* soft X-ray (SXT) images are used to associate the observed shifts with loop structure. The oscillations are strongest and in phase at the loop apex indicating an anti-node at the loop top and nodes at the footpoints. Examples are shown for loop lengths between 80 and 500 Mm. The oscillation period is roughly equal to twice the loop length divided by the sound speed in the loop, consistent with the fundamental of slow mode standing waves.

Key words: Sun; active region; oscillations; UV radiation.

1. INTRODUCTION

The SUMER spectrometer has recently revealed hot active region loops oscillating with a period equivalent to twice the sound crossing time along the loop Wang et al. (2002, 2003a). These oscillations only occur in loops impulsively heated to a temperature greater then 6 MK. Examples discussed to date are for strong, isolated events. The effects of multiple heating and oscillation events on the active region energy balance has not been considered. In this paper we present the time series of Fe XIX emission from an active region over a period of about 4 days and compare the frequency of heating and oscillation events at different heights in the corona. We also look at the effect on the cooler Ca XIII (4 MK) line. Every hour or so *Yohkoh* soft X-ray (SXT) images of the loop structure are available and we are able to determine the oscillation characteristics with respect to the loop length and the distance from the loop apex.

2. OBSERVATIONS

The active region as seen in the EIT 195 Å filter over the four days is shown in Figure 1. The SUMER intensities for the lines Fe XIX, Ca XIII and S III are illustrated in Figure 2. The Fe XIX line is the most dynamic. There is a trend from short bursts of flaring activity on the 17 Sep to longer lasting and broader events on the 19 Sep. When there is a strong Fe XIX brightening, the Ca XIII responds with a small brightening about an hour later (*e.g.* 1:00 on 17 Sep). Some events cause Ca XIII dimming (*e.g.* 3:00 on 18 Sep). More details of the SUMER intensities variations are shown in Figure 3. This shows that from 10:00 to 23:00 17 Sep, there are about 25 Fe XIX bursts. All that one sees in Ca XIII is an occasional dimming and in only two cases any significant brightening. Both the delay and the dimming behaviour has been seen in extreme ultraviolet (EUV) and soft X-ray studies (*e.g.* Ashwanden & Alexander 2001; Harrison et al. 2003). If the Ca XIII can be thought of as a proxy for EUV emission and the Fe XIX for the soft X-ray, it can be concluded that the EUV images reflect only a fraction of the flaring in active region loops. The lower panel in Figure 3 is the time series of EIT 195 Å fluxes taken from the position of the SUMER slit, as expected from the Ca XIII behaviour, the EIT 195 images show nothing spectacular.

The S III emission is mostly in the south where the slit cuts across lower heights (10–20 Mm). It gives the impression of cold ejecta running south-north, parallel to the limb, with a speed of about 40 km s^{-1}. These SUMER images are deceptive because we are only seeing a narrow, fixed section of the loops and the height from the limb also increases south-north so it may be a front moving outwards. Simultaneous cold line images are required before conclusions can be drawn about the dynamics of the cold ejecta. There is, however, one interesting detail in the S III with respect to loop heating. There are faint brightenings that illuminate almost the whole slit. The strongest example is around 7:00 on 17 Sep in Figure 2. In Figure 3 there is something at 21:00. This effect has been seen in other flare events at the time of hard X-ray bursts and is caused by resonance scattering in the corona when the chromosphere brightens. It is another indication that the energy in these events is more than we can measure with available instruments.

3. FE XIX OSCILLATIONS

Doppler shift oscillations were reported by Kliem et al. (2002), Wang et al. (2002), (2003b). They are only seen in flare lines like Fe XIX and Fe XXI with formation temperature greater than 6 MK. The oscillation periods, in the range 15–30 min for 150 to 500 Mm loops suggest slow mode standing waves. With the help of SXT images we can determine whether there is a node at the top or at the footpoint and thus deduce the trigger position. A loop top node would indicate triggering at the top since this would naturally produce opposite directed flows from this point. An anti-node at the top probably indicates footpoint excitation but suitable simulation studies still have to be performed.

Proceedings of the SOHO 15 Workshop - Coronal Heating, St. Andrews, Scotland, 6-9 September 2004
(ESA SP-575, December 2004)

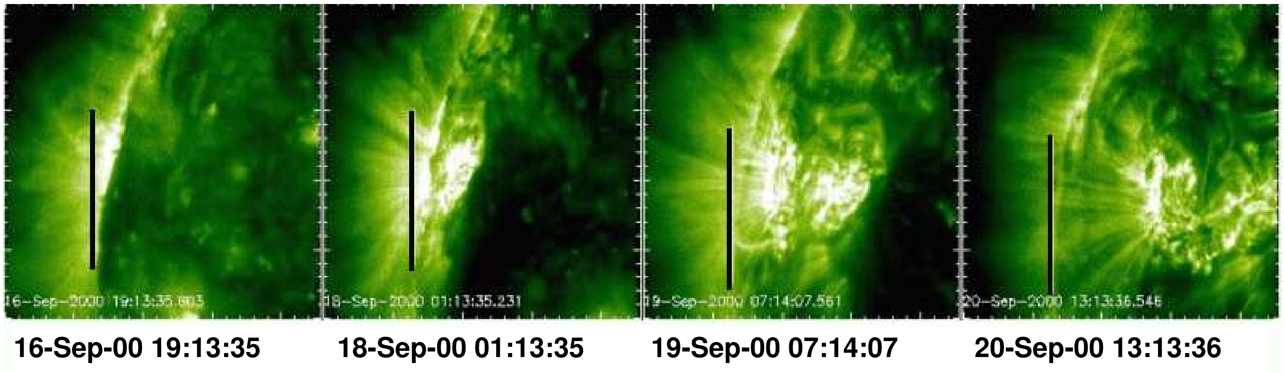

Figure 1. EIT 195 Å filter images of the loop system AR 9167. The position of the SUMER slit is marked as a black vertical line.

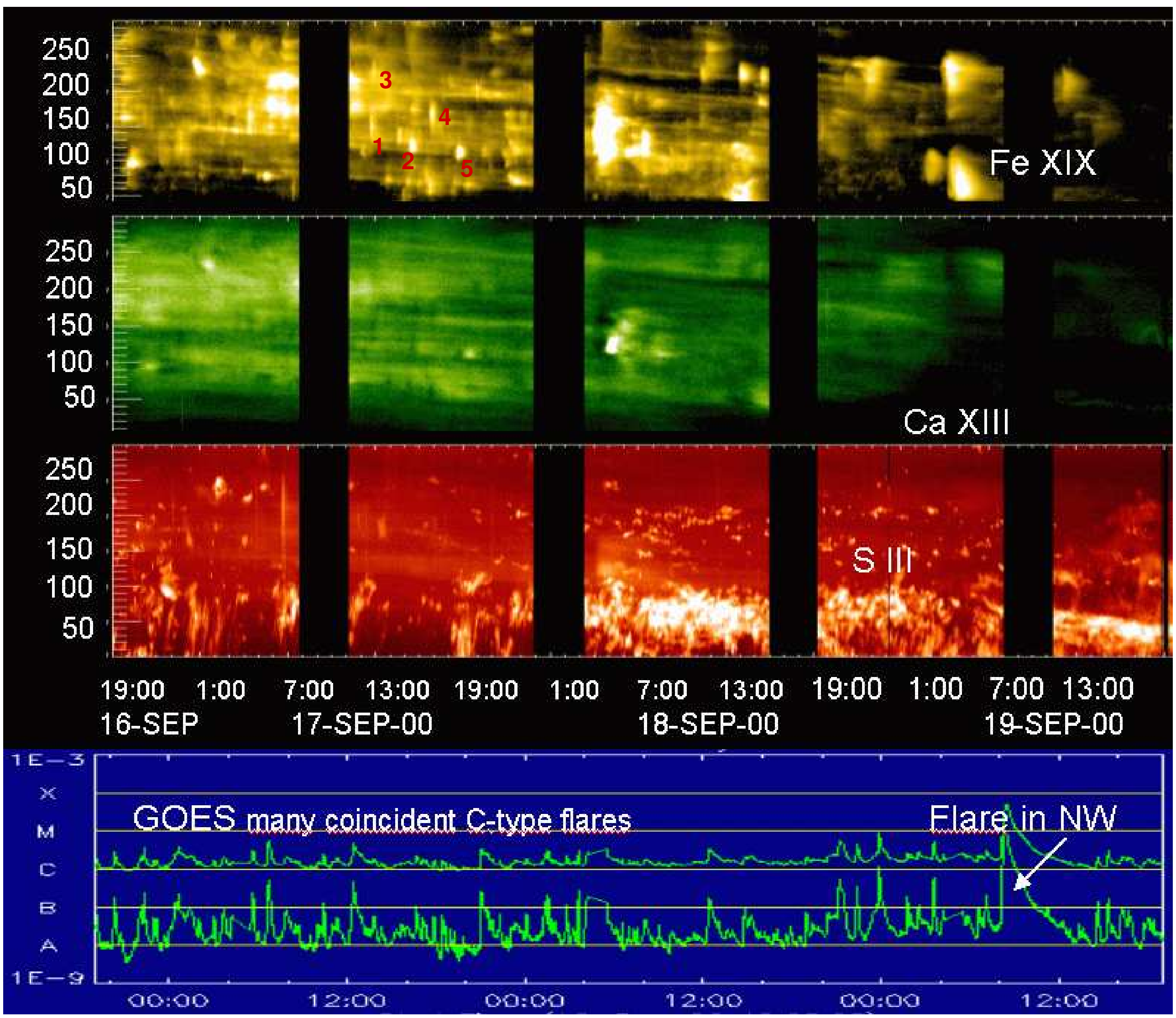

Figure 2. The SUMER line intensities detected at the slit positions shown in Figure 1. Underneath are the GOES soft X-ray fluxes

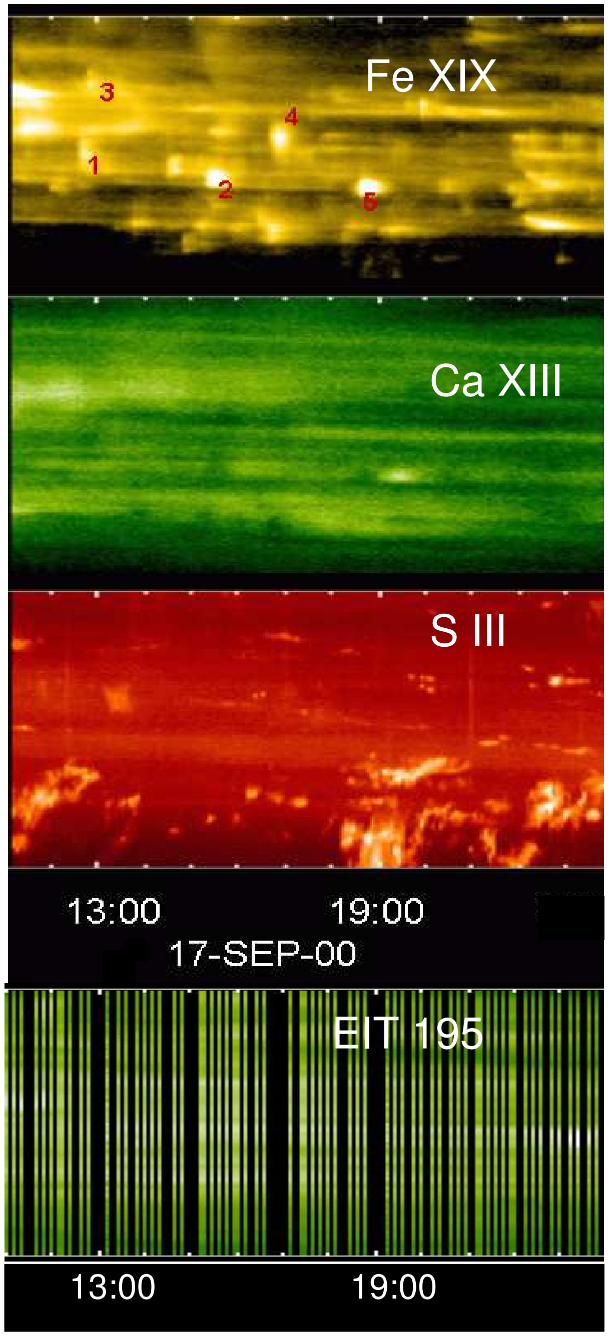

Figure 3. The SUMER line intensities detected at the slit positions shown in Figure 1 for the period 11:00-23:00 17 Sep. Underneath are the EIT 195 Å fluxes at the same position. The cadence of EIT is much less than SUMER.

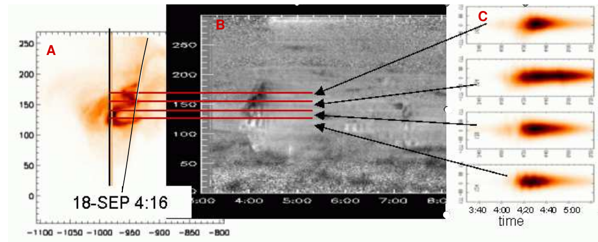

Figure 5. A) SXT image with slit position and solar limb; B) SUMER Fe XIX *Doppler Velocity. Black (white) is blue (red) shift of 50 km* s^{-1}*; C) Time variation of SUMER line profiles integrated over 5 spatial pixels centered at the positions with red lines*

3.1 Small loop tops

From 17-18 Sep, the active region was just rounding the limb and loops with a typical length of about 100 Mm had tops coinciding with the slit. In Figure 4, 11 hours of Fe XIX Doppler velocity are shown. The numbered events are the same as those on the Fe XIX intensity image in Figures 2, 3. Events 1, 4 and 5 show Doppler oscillation. Events 2 and 3 only brightened. The typical oscillation periods are 8-10 min, which is roughly $2L/c_s$, where c_s is the sound speed $\sim$ 400 km s^{-1} and L is the loop length.

3.2 Loop top and leg comparison

As seen above, not all Fe XIX brightenings are associated with Doppler oscillations. The example in Figure 5 shows a large brightening event with Doppler oscillation across only half its length. In this example, several adjacent loop systems brighten simultaneously but the SUMER slit only cuts across one set of loop tops. The rest of the brightening is from half way up the loop leg and this has much weaker Doppler oscillation. Thus it seems plausible that those brightenings without oscillation are from loop legs and those with are from loop tops.

3.3 Large loop oscillation

A good example was seen on 19 Sep. There are two oscillating loop systems (Figure 6). Only the lower one has simultaneous SXT images at the onset. Here the whole loop top is oscillating in phase. There is no indication of a node. The observed velocities in the other system, however, show distinctly different character north and south and it looks as though there may be a node at the loop top. On inspection of the SXT image one sees that the slit at this position crosses an upper and lower loop system and the changeover occurs at the slit position where the velocities change sign thus explaining the node-like character in the velocity map.

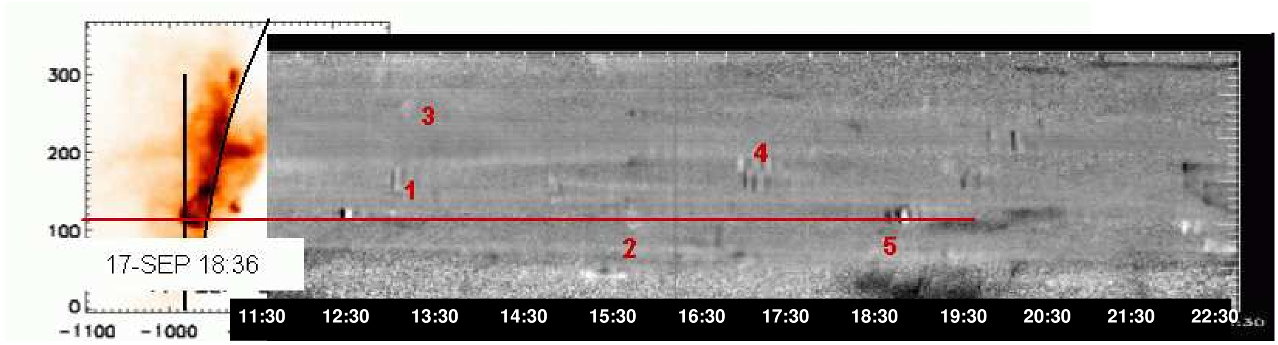

Figure 4. Fe XIX *Doppler shift over a period of 11 hours starting 11:30 17 Sep. The event numbers are the same as in Figures 2, 3. The SXT image on the left is taken during event 5.*

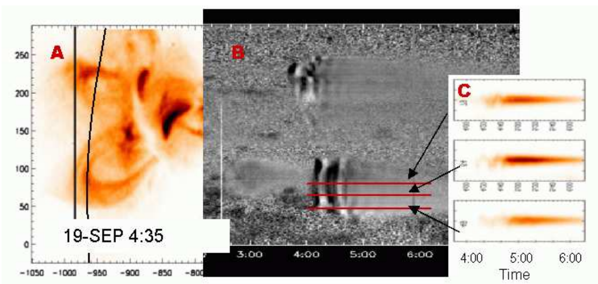

Figure 6. Example of loops with Doppler oscillations. A) SXT image with slit position and solar limb; B) SUMER Fe XIX *Doppler Velocity. Black (white) is blue (red) shift of 50 km s^{-1}; C) Time variation of SUMER line profiles integrated over 5 spatial pixels centered at the positions with red lines*

4. CONCLUSIONS

There are many heating events in active region loops that can only be seen at temperatures greater than 6 MK. We see them clearly in SUMER Fe XIX line emission. At the time of some events the cold line S III brightened along a large fraction of the slit indicating a burst of chromospheric brightening on the disk. EUV emission, which reveals the dynamics of the 1-5 MK plasma, sees only a fraction of the activity.

The rapid heating events trigger loop oscillations. The oscillations are strongest and in phase at the loop tops, suggesting an anti-node at the apex. The period is twice the sound crossing time of the loop, as expected for the fundamental mode of standing sound wave oscillations. In this case, nodes would be at the footpoints and this implies footpoint excitation.

ACKNOWLEDGMENTS

The SUMER project is financially supported by DLR, CNES, NASA and the ESA PRODEX programme (Swiss contribution). SUMER is part of SOHO, the Solar and Heliospheric Observatory, of ESA and NASA.

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