Evidence for in situ heating in active region loops

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Abstract

We report new observational results and insights in the energy release during transient events on sub-flare level, which seem to be a common feature of active region loops. Our work is based on multi-temperature observations obtained high above the limb by SOHO/SUMER. We conclude that the energy input into the loop system is initiated at one and only one foot point by an **asymmetric impulsive** mechanism. This trigger does **not** seem to be connected with **any bulk flow** and there is no indication that the plasma in the loop is replenished or replaced. These observational facts rule out some of the heating models under discussion. The electron density, N_e however, increases significantly during such events. If no new material is added to the local plasma, then the N_e increase can only be explained by a rapid volume decrease, i.e., by an **in-situ pinch effect**, compressing and heating the affected plasma.

The observations

Here we combine results reported by Wang et al. (2005, paper I), Feldman et al. (2004, paper II) and Curdt et al. (2004, paper III).

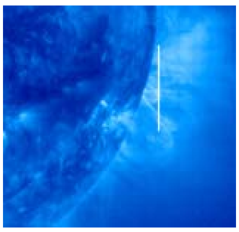


Fig.1 The scene

In all studies the spectrometer slit was – as shown on this EIT 171 image – pointed to a position 50 - 100“ off the disk and spectral scans were taken in sit-and-stare mode including (among others) simultaneously the emission lines

- Fe XIX 1118 Å (6.7 MK)
- Fe XVII 1154 Å (2.9 MK)
- Ca XIII 1133 Å (2.0 MK) and
- Ca X 1116 Å /2 (0.7MK) .

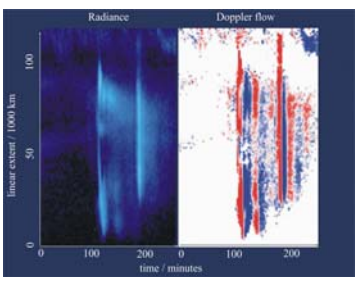
Another window around the Fe XXI 1354 line was also used.

As a primary result multi-temperature *x-t* and *v-t* maps were obtained (spectral radiance and Doppler shift along the slit versus time) from many observations.

Immediate results

Fig.2: Coronal seismology.

As a surprising new result it came out that Doppler oscillation events (DOE) seem to be a common feature in hot active region loops. Wang et al. have reopened the field of coronal seismology. While many details are known now about the oscillations, little is known about the trigger. From recent work we now suggest that the oscillation is just a by-product of the impulsive start of isolated heating events.



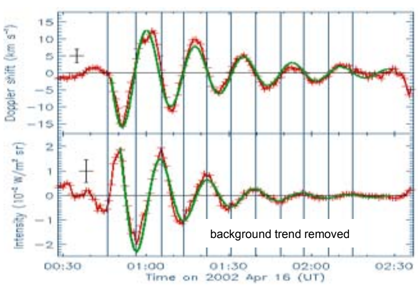
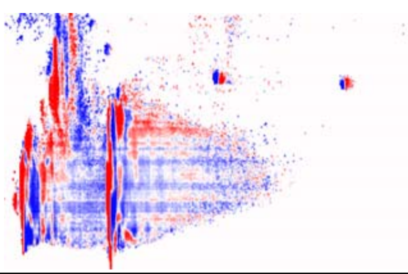


Fig. 3: Coronal organ pipes.

Doppler shift and spectral radiance (background trend removed) of the Fe XIX emission during a DOE. After a sudden start, the loops oscillate about a zero position corresponding to the rest wavelength. The phase shift is exactly 90° (Wang 2002). This is a strong argument in favour of an axial slow mode standing wave.

Fig.4: The rule of unidirectionality.

40% of the DOEs are multiple events like in this Doppler map. It seems as if a follow-up event is just a repetition, identical to its predecessor and it is most remarkable that multiple events always start in the same direction. This is a strong argument for asymmetric energy input and proves that the activity comes from one and only one footpoint.



Diagnostic results

Diagnostic methods have been used in paper II for several cases to derive the electron density N_e, the electron temperature T_e and the elemental composition of the flaring plasma.

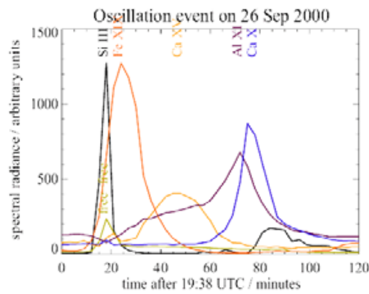
The elemental abundances of low-FIP calcium and iron are enhanced by a factor of 8 – 10 relative to photospheric values.

A typical value of $N_e = 1.2\ 10^{10}\ cm^{-3}$ has been found as lower limit. This is at least two orders of magnitude higher than in a quiescent coronal loop.

T_e peak values vary between 4.9 10^6 K and 9.0 10^6 K. Similar values have also been reported in papers I & III. The maximum is reached within minutes.

Fig. 5 Multi-temperature light curves

During the initial phase emission is seen in all temperatures, peak temperatures are reached within minutes. The cooling lasts over 1 hour and comes to a sudden end. During the cooling the plasma is isothermal, i.e. at one temperature at a given time.



Argumentation

(1) No systematic bulk flow > 2 km/s is observed during DOEs (papers I & II & III).

(2) The footpoints behave differently, there is only one active footpoint. DOEs have an asymmetric impulsive start from this active footpoint.

(3) Abundances are coronal, not photospheric.

(4) Double events can only have identical nature, if nothing has changed.

(5) The cooling takes much longer than expected from radiative losses. This suggests that moderate heating continues for a while.

Each of these arguments is in conflict with the popular model of chromospheric evaporation, which assumes that chromospheric plasma fills the loops and replenishes the coronal plasma. Our observations, however, imply that no new material is added to the local plasma.

The observed increase in N_e can only be explained by a substantial decrease in volume. Therefore an in-situ compressive mechanism is required.

The empirical model

Following the argumentation of Feldman et al. (2004) we assume that the loop is being compressed by an azimuthal magnetic field ***H***, which is based on an axial current $\boldsymbol{j} = c/4\pi\ \nabla \times \boldsymbol{H}$. Such a magnetic field exerts pressure on the coronal plasma and consequently compresses and heats it. In this picture, a discharge front starts suddenly at the footpoint with negative polarity and runs with a speed of 50 to 100 km/s along the loop as derived from the initial peak Doppler flow and from the timing in those cases, where both loop legs are imaged by the slit. This impulsive mechanism also imposes a mechanical shock to the elastic system, the starting point of an axial oscillation. A similar mechanism is known as z-pinch and used in tokamaks and high-energy lasers.

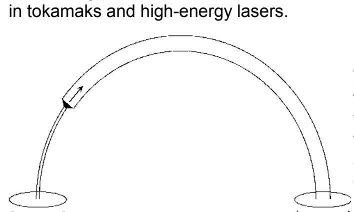


Fig. 6: Cartoon of the empirical pinch model.

The presented model can explain all observed features, in particular the rule of unidirectionality. It requires a potential difference between the footpoints and a dominant polarity of the trigger area. This is also true for the magnetic polarity of the active footpoint. More observations are needed to refine and test the presented model.

References

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