PHYSICAL CONDITIONS IN A LARGE FLARE LOOP ON 22 NOV 1980 DERIVED FROM SMM OBSERVATIONS

B. Sylwester[1], J. Sylwester[1], J. Jakimiec[2], A. Fludra[2],
R.D. Bentley[3], J. Schrijver[4]

[1]Space Research Centre, Wroclaw, Poland

[2]Astronomical Observatory, Wroclaw, Poland

[3]Mullard Space Science Laboratory, Dorking, U.K.

[4]Laboratory for Space Research, Utrecht, Holland

ABSTRACT. We present the study of a large X-ray loop related to the H-alpha 2N flare close to the center of the solar disc. The FCS, BCS and HXIS data from Solar Maximum Mission have been used in the analysis. We have derived the temperatures, densities and the geometrical parameters (length, diameter) for a hot core and for a cooler envelope of the flaring loop. For the hot component we have obtained the time behaviour of each of the term included in the energy balance relation.

ФИЗИЧЕСКИЕ ПАРАМЕТРЫ БОЛЬШОЙ ВСПЫШЕЧНОЙ ПЕТЛИ ПОЛУЧЕННЫЕ ИЗ НАБЛЮДЕНИЙ SMM 22 НОЯБРЯ 1980 ГОДА: В работе представлено исследование большой петельной структуры связанной с Н-альфа вспышкой балла 2 , которая произошла вблизи центра солнечного диска. В анализе употреблялись данные полученные спутником SMM с помощью приборов: FCS, BCS и HXIS. Была получена температура, плотность а также геометрические параметры для горячего ядра и холодной оболочки вспышечной петли. Для горячего компонента были вычислены временные изменения всех членов, входящих в уравнение энергетического баланса петли.

FYZIKÁLNE PARAMETRE VEĽKEJ ERUPČNEJ SLUČKY, POZOROVANEJ 22. NOVEMBRA 1980 NA DRUŽICI SMM. V práci je študovaná veľká slučková štruktúra, súvisiaca s výskytom erupcie, ktorá mala v H-alfa importanciu 2N a nachádzala sa blízko centra slnečného disku. Pri analýze boli použité pozorovacie údaje získané na družici SMM prístrojmi: FCS, BCS a HXIS. Pre horúce jadro a pre chladnú obálku erupčnej slučky boli odvodené hodnoty teploty a hustoty a tiež geometrická pa-

rametre (dĺžka a priemer). Pre horúcu zložku bola vypočítaná časová závislosť všetkých členov, ktoré sa vyskytujú v rovnici energetickej rovnovéhy slučky.

The flare of 22 November 1980 has been already a subject of the paper by Chung-Chieh Cheng and Pallavicini, (1984). From a comparison of the X-ray images with coaligned H_α images (see Fig. 4 in their paper) they deduced the magnetic field configuration of the flare. According to them the observed X-ray disc loop-like structure was most likely a single loop with the footpoints anchored in the two brightest H_α regions, which appeared to extend along the magnetic inversion line separating two active regions.

Here we have quantitatively analysed the X-ray data related to this flare. The data consist of the soft and the hard X-ray observations from SMM. The FCS data are the spectroheliograms of the flare made simultaneously in 5 spectral lines (OVIII, NeIX, MgXI, SiXIII, SXV) at 8 times on the decaying phase of the flare. The BCS spectra of CaXIX and the HXIS fluxes in 4 energy channels (from 3.5 to 16 keV) for the whole loop, cover in addition the rising phase of the flare.

The 22 Nov 80 flare was a slowly evolving and large scale event. It was connected with class 2N flare in H_α, and situated away from the central part of the active region. It was located in a spotless area, in between two adjacent active regions (NOAA 2793 and 2794) near the disc center (at N12 W02).

In the soft X-rays the flare appeares as a large loop-like structure, stable during the 20 min period of observations by FCS.

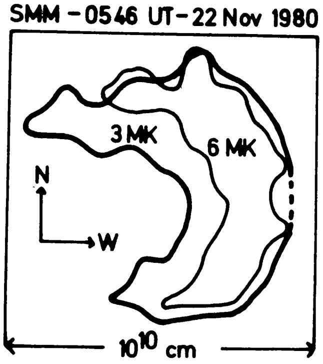

Fig. 1: Intensity contours drawn at 0.35 of the maximum intensity as obtained from deconvolved FCS images. Contours denoted 3 MK and 6 MK correspond to image measured in Mg XI and S XV channels. The temperatures have a sense of a mean temperature of the line formation.

In Fig. 1 the deconvolved intensity contours (0.35 I_{max}) of relatively low-temperature radiation (MgXI, thick line) and higher-temeprature radiation

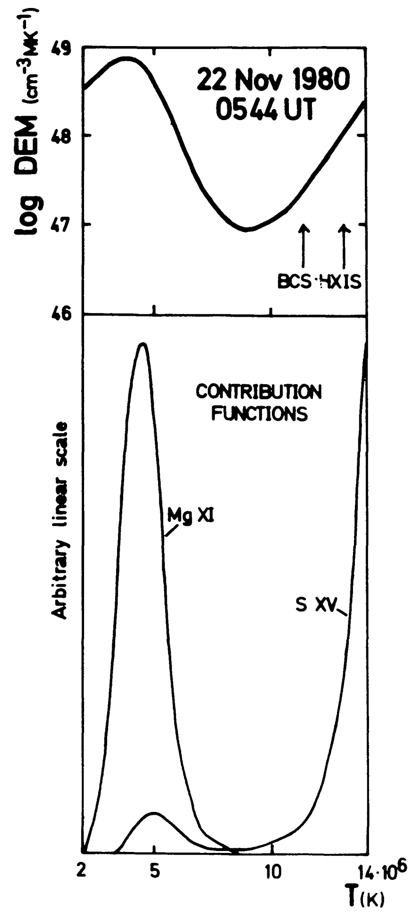

Fig. 2: Top: Temperature distribution of the Differential Emission Measure (DEM). Characteristic temperatures estimated from the BCS and HXIS data (see text) are indicated by arrows.
Bottom: Contribution functions indicating that the 3 MK isophote in Fig. 1 reflects the appearance of the low temperature component, while the 6 MK isophote is intermediate between the hot and the cool components.

(SXV, thin line) at 0546 UT are shown. One can see that the loop-like structure observed in the soft X-rays consists of the hotter and thinner core and of the cooler and wider envelope. The two component character of the emitting plasma is apparent also on the differential emission-measure-temperature distributions. In Fig. 2 one such model obtained from FCS data at 0544 UT is shown. The DEM-distribution has been calculated by the routine developed by Sylwester et al., (1980). In Figure 2 the contribution functions (the product of the model and of the emission functions) for two individual lines are shown.

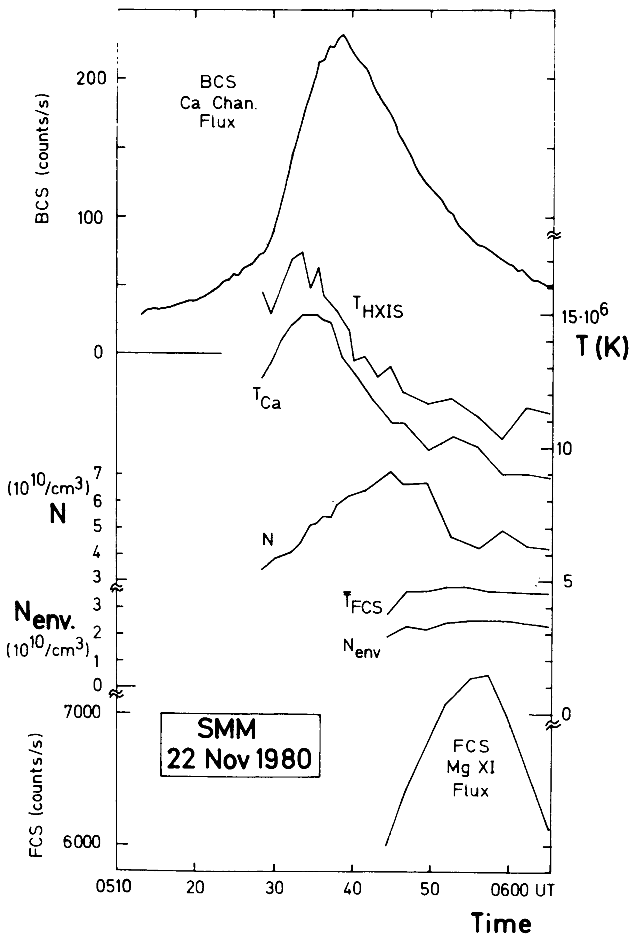

Fig. 3: The time variation of the important physical parameters for the hot and the cool flare components. Bottom three curves are derived from the FCS data available after 0544 UT only. Upper four curves are related to the hot component.

They give the information in which temperature interval a given line is effectively formed.

In Fig. 3 the time variations of the values of different parameters of both components, and two characteristic light curves are shown. The T_{HXIS} for the core has been obtained from the counting rates measured in channel 1 (3.5-5.5 keV) and channel 3 (8.0-11.5 keV) by HXIS instrument and should be treated as maximum temperature of the plasma contained in the core. T_{Ca} represents the mean temperature of the hot core and has been derived by fitting the BCS Ca spectra (see Lemen et al., 1987). The total emission measure $\mathcal{E}$ of the hot plasma component has been derived in this fitting process also. The para-

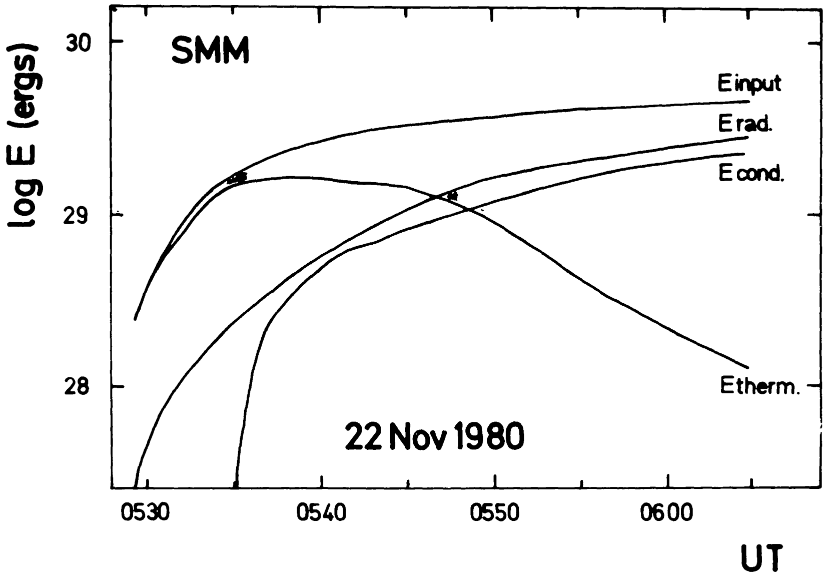

Fig. 4: The time variation of the components of the integrated energy balance equation for the hot loop ($T > 8$ MK)

meters for the cooler component ("envelope" in Fig. 3) were obtained in the following way: the temperature $\overline{T}_{FCS}$ was taken as corresponding to the maximum of DEM distributions (see Fig. 2), the density N_{env} was obtained from the total emission measure $\mathcal{E}_{env}$ calculated for this component, while the volume $V = 3.43 \times 10^{28}$ cm^3 was obtained from MgXI deconvolved images, assuming circular cross-section of the loop. ($N_{env} = \sqrt{\frac{\mathcal{E}_{env}}{V}}$

With the help of the method LEBAN (loop energy balance analysis) presented in the paper by Sylwester and Sylwester (1987), the total loop length of 1.33×10^{10} cm with cross section area of 7.78×10^{16} cm^2 were obtained based on time variations of T_{HXIS}, T_{Ca} and $\mathcal{E}$.

The length derived theoretically is in a very good agreement with that seen from the FCS images (1.45, 1.29, 1.11 x 10^{10} cm for OVIII, MgXI and SiXIII respectively). The derived "effective" diameter of the loop (~4 arc sec) is much less than the resolution of the FCS collimator and thus the loop width cannot be resolved even on the deconvolved images. The contour corresponding to $T = 6$MK in Fig. 1 establishes an upper limit for the core dimensions. The values of the loop length and the "effective" loop diameter allow to investigate the changing role of various terms included in the energy balance equation for the total loop (the hot component):

$$\frac{d\,E_{thermal}}{dt} = E_H - E_r - E_c \qquad (1)$$

where E_H is the energy deposition rate (erg/s) into the loop, $E_{thermal}$ is the loop thermal energy, E_r is the rate of the energy losses due to radiation, E_c is the rate of energy losses due to the conduction (away from the region $T > 8$ MK).

Following the LEBAN method we express

$$E_{thermal} = 3NkTV = 3\ k.T.\ \sqrt{\mathcal{E}.V} \qquad (2)$$

$$E_H = e_H \cdot \beta \cdot V \qquad (3)$$

where β is the portion of the loop where the energy depossition takes place, and

$$e_H = \varkappa_o\, T_{max}^{3.5} / L^2 \qquad (4)$$

Here $\varkappa_o$ represents the thermal conductivity and L is the loop semilength.

$$E_r = \mathcal{E} \cdot P_r(T) \qquad (5)$$

and $P_r(T)$ we have taken after Rosner et al.,1978.

The calculated evolution of all the energy balance equation components are shown in Fig. 4.

It is worth noting that during the initial phase nearly all of the energy deposited $E_{input} = \int_0^t E_H.dt$ is used to increase the thermal plasma energy. With the time, the mean plasma density N rises as shown in Fig. 3 and the radiative loses $E_{rad.} = \int_0^t E_r \cdot dt$ becomes more and more important. After the peak of the energy input rate (at 0535 UT) the role of conductive loses $E_{cond.} = \int_0^t E_c \cdot dt$ grows to reach at the end of the event a level close to the total radiative loses.

A summary of the values of important parameters derived for the hot and cool flare components is given in Table 1. The hot component values are all obtained theoreticaly following the LEBAN method. On the contrary, the geometrical parameters for the cooler component were obtained from the FCS deconvolved images. The two values given in this case for the diameter of the loop refere to the apex and the footpoint respectively.

In conclusion, the 22 Nov flare seems to be a good example of a loop structure which is in a quasi-stationary state for a long time during decay. For this period the relation between the maximum temperature and the pressure is governed by a static loop scaling law (Rosner, Tucker and Vaiana, 1978). In the initial phase, the loop containing the hot component plasma can be considered as a thermaly isolated system with conductive loses unimportant.

Deconvolved FCS images of the flare together with results of the differential emission measure modelling and the LEBAN approach consistently indicate that the flare comprises two loops of similar length with different tempe-

Table 1

Parameters of the 22 November 1980 flare

	HOT COMPONENT	COLD COMPONENT	
Length of the loop [cm]	1.33+10	1 3 1.45+10	
Diameter [cm]	3.15+8	2.42+9	1.19+9
Area [cm^2]	7.78+16	4.58+18	1.12+18
Volume [cm^3]	1.03+27	3.43+28	
Maximum density [cm^{-3}]	7.10+10	2.52+10	
Maximum pressure [dyne cm^{-2}]	107	16	
Total energy deposited [erg]	4.6+29	8.23+26	
The heating rate$_{Max}$ [erg cm^{-3} s^{-1}]	0.488	0.016	

ratures, densities, pressures and heating rates. The narrow hot loop is placed most probably within the wider cooler one; the two are magnetically isolated.

ACKNOWLEDGEMENTS

We wish to acknowledge the work of the principal investigators L.W. Acton, J.L. Culhane and A.H. Gabriel and all the XRP team and all the HXIS team whose efforts have led to availability of the data used.

REFERENCES

Chung-Chieh Cheng, Pallavicini, R.: 1984, Solar Phys. 93, 337.
Leman, J.R.: 1987, in preparation.
Rosner, R., Tucker, W.H., Vaiana, G.S.: 1978, Astrophys. J. 220, 643.
Sylwester, J., Schrijver, J., Mewe, R.: 1980, Solar Phys. 67, 285.
Sylwester, J., Sylwester, B.: 1987, in preparation.
Withbroe, G.L.: 1981, in Solar Active Regions. ed. Frank Q. Orral, Colorado Associated University Press, Boulder, 199.

DISCUSSION

J. Staude
Did you always use the ionization equilibrium calculations based on stationary steady state asumptions and is this justified during flares ?

J. Sylwester
Yes, we assume stationary conditions for the ionisation state of the plasma. Our analysis deals with the decay phases of flares. During decay phase the characteristic time for the plasma temperature variations is much longer ($\tau > 100s$) than the time to reach the equilibrium state. This time can be estimated as $\tau_{eq} \sim \frac{10^{12}}{N_e}$, where N_e is the plasma density (per cm^{-3}). With typical $N_e \sim 10^{11}$ cm^3 (during flare decays) $\tau_{eq} \sim 10s$. Thus the assumption of the stationary ionisation conditions is valid.

COMMENT

to the contribution Křivský et al. from page 161:

B. Kálmán
The flare of June 3, 1982 was observed in white light by a Hungarian amateur astronomer, so it was definitively a white-light flare. In the Debrecen Observatory we are preparing a study of this group, together with the drawing of the flare. Unfortunately the time of the observation is not very exact.