MODEL OF SLOWLY EVOLVING FLARE

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ABSTRACT: *A gradual rise and fall flare with a duration of about one hour was observed on June 10, 1980 in the radio (Toyokawa and VLA), optical (Bing Bear) and XUV (SMM satellite) ranges of wavelengths. The flare developed as a large loop connecting two regions of opposite polarity in a pre-exisisting active region. A model of the differential emission measure of the loop observed at three different stage of the flare is deduced from the analysis of the XUV images in C IV (1549 A), O VIII (18.97 A), Ne IX (13.45 A), Mg XI (9.17 A) and Si XIII (6.65 A) emission lines. The differential emission measure as a function of temperature is controlled by the conductive flux via the temperature gradient; the evaluation of the divergence of the conductive flux is used in the energy balance to have information on the power deposition function.*

1. OBSERVATIONS

Preliminary results of the analysis of a solar flare, which took place on June 10/11, 1980 and was observed in all ranges of wavelengths from X-ray to radio, are presented. In this analysis only UVSP: CIV and XRP: FCS Ch. 1 to 4 rasters are taken into account. The peculiar characteristic of the flare is the estremely slow rate of intensity increase and fall and its long duration (about one hour).

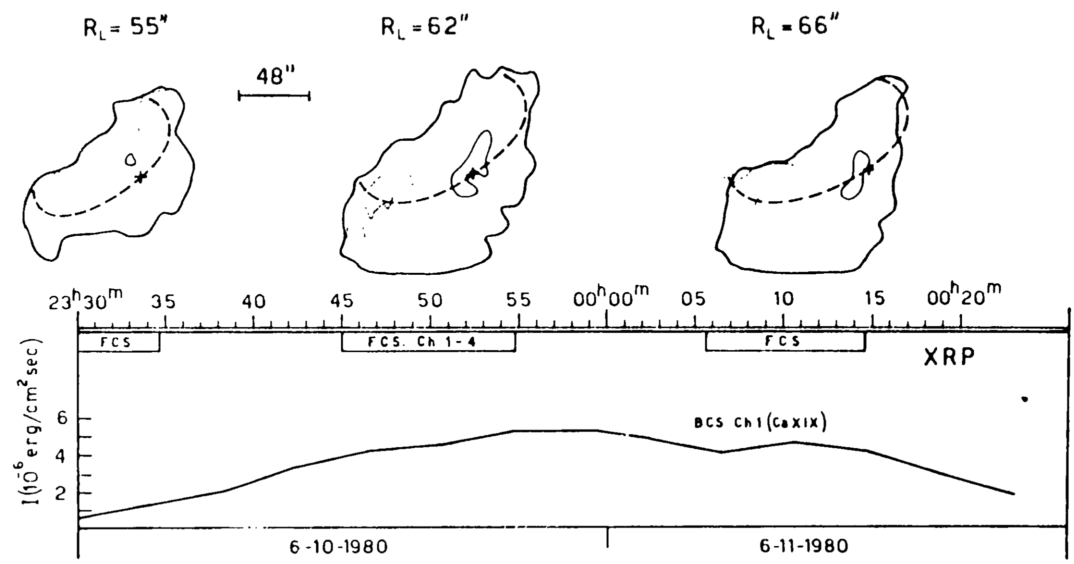

fig.1

In fig.1 the time behaviour of the whole flare intensity, as observed by XRP:BCS (lower panel), is presented, the windows indicate the time intervals in which XRP:FCS rasters and UVSP CIV

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dopplegrams are available. In the upper pannel the morphology of the flare resulting from UVSP and XRP:FCS contour levels, recorded in three different time intervals, is shown: XRP contour levels correspond to the level inside which the flux has been integrated in all spectral lines (thick line) and the level corrisponding to 0.8 I_{max} in channel 4 [SiXIII] (thin line). UVSP (dotted line) corrispond to contour level 0.1 I_{max}. The dashed line is the projection on the disk of a semicircular loop, of radius R_L lying in the local vertical plane, and the cross is the projection of its maximum. Notice the coincidence between the cross and the maximum of Si XIII.

2. THE LOOP MODEL

The theoretical luminosity $\Phi(\lambda)$ (erg s^{-1}) in an optically thin line is given by:

$$\Phi(\lambda) = \int_{T_1}^{T_c} f(\lambda,T)\, n^2\, dV \qquad (1)$$

where $f(\lambda,T)$ is the power emitted per unit emission measure in the line, n is the electron density in the volume dV, T_c and T_1 are the maximum and minimum temperature of the loop.For $T<T_1=2.\ 10^4\ {}^oK$ the assumption of optically thin line is no longer valid. The power emitted per unit emission measure $f(\lambda,T)$ has been evaluated by means of a computer code developped by Landini and Monsignori Fossi (1984) for low density and high temperature plasmas.

Loop models for the solar active regions have been extensively investigated in the last 15 years (Rosner et al.1978, Landini et al.1985 and references therein). Most of these studies consist in the evaluation of the differential emission measure (d.e.m.=n^2 dV/dT) as a function of temperature from which the theoretical line intensity can be computed and compared with observations. The differential emission measure (d.e.m.) dipends on the temperature gradient which is defined by the conductive flux. For instance in a stationary coronal loop with costant pressure p_0 and costant cross section S, the energy balance equation gives the following form for the conductive flux :

$$F= -A\, T^{2.5}\, dT/dl = F_0(T/T_c)^{\beta}[(1-(T/T_c)^{\delta}]^{1/2} \qquad (2)$$

In eq.2 l is the cordinate along the loop, β depends on the radiative losses approximation and δ on the specific power law approximation used for the energy supply (for istance radiative losses proportional to $n^2T^{-0.5}$ give β=0.5 and power supply indipendent on the temperature gives δ=2.5).
Deriving, in the above assumption, the d.e.m. from eq.2 and putting it in eq.1, high temperature line intensities are very well reproduced, while low temperature one ($T< 3.\ 10^5\ {}^oK$) are strongly understimated .This fact have suggested to Monsignori Fossi and Landini (1988) to multiply the rigth hand side of eq..2 by an exponential term: exp(T/T_0) where T_0 is a free parameter ($T_1<T_0<T_c$). With this form of F and the assumption p_o=const., the d.e.m. becomes:

$$d.e..m.=n^2dV/dT=(p_0{}^2/4k^2)(10^{-6}/F_o)T^{0.5}(T/T_c)^{-\beta}\{exp(T_o/T)[1-(T/T_c)^{\delta}]^{-1/2}\}$$

Assuming log T_o= 5.2, the theoretical mean intensity (erg cm^{-2} s^{-1} st^{-1}) in each line is evaluated and the free parmeters β, δ, T_c and the normalization factor $Sp_0{}^2/F_0$ are deduced from a χ^2 fit with the observations.

Table 1

Time	χ^2	$\log T_c$	δ	β	$S\, p_0{}^2/F_0$
$23^h\ 26^m$	.6	6.63$\pm$.02	0.5$\pm$.1	0.1 $\pm$.15	9.5 10^{12}
$23^h\ 45^m$	1.5	6.72$\pm$.03	0.5$\pm$.1	0.2 $\pm$.2	1.5 10^{13}
$00^h\ 06^m$	1.	6.74$\pm$.02	0.5$\pm$.1	0.15 $\pm$.15	2.4 10^{13}

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The procedure has been applied to the three sets of data shown in fig.1 (top) to have an insight of the time variation of the loop structure during the event. The results of the fit are given in the table 1. Uncertainty of the normalization factor Sp_0^2/F_0 is about $\pm$ 20%.

By integration of the d.e.m. function the temperature profile may be obtained: fig 2 shows the temperature profile for the time 00^h 06^m U.T.: vertical bars give the temperature derived from the averaged line intensity in each section of 10" thickness, perpendicular to the loop length and assumed isothermal.

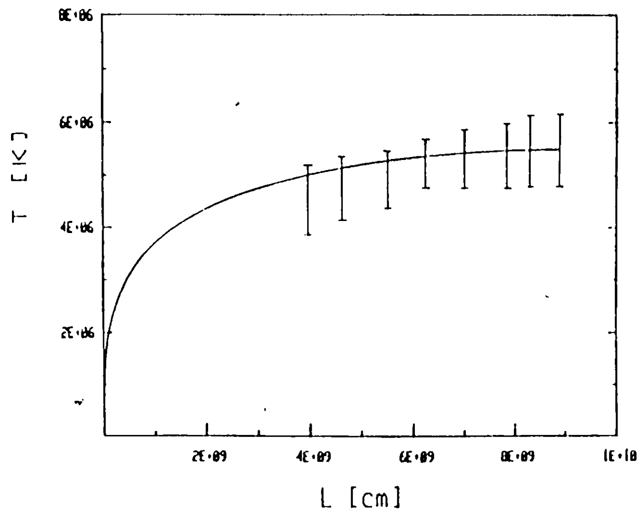

fig.2

Since the length l and the section S can been measured on the images, F_0 and the pressure p_0 may be evaluated. Uncertaities of F_0 and p_0 amount to $\pm$15%. Table 2 shows, for each time interval, the semilength and section of the loop and the pressure

Table 2

Time	l/2 (cm)	S (cm^2)	p_0(dyn/cm^2)
23^h 26^m	7.9 10^9	2.8 10^{18}	10.
23^h 45^m	8.6 10^9	4.4 10^{18}	15.
00^h 06^m	8.9 10^9	4.4 10^{18}	18.

Table 1 and 2 show that the pressure increases by about a factor of two, while the maximum temperature increases less than 30% .

The small variation presented by the parameters entering in the model justifies the use of a stationary model to study this event. For each time interval the conductive flux and its divergence may be computed from the temperature profile; the temperature profile also allows to compute the divergence of the enthalpy flux which for sufficent low velocity gives the convective contribution to the energy balance. Since the radiative losses are known as a function of pressure and temperature, the balance among all these terms and the enegy supply along the loop allows the determination of this latter, if the quasi stationary hypotesis is valid. Fig.3 shows the trend of the energy balance terms (ergs $cm^{-3}sec^{-1}$) along the loop as a function of temperature at time 00^h 06^m; the full line indicates the

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radiative losses as computed using Landini and Monsignori Fossi spectral code (1984); the dotted line gives the divergence of the conductive flux which may be deduced from the model; dashed and dotted line gives the divergence of the enthalpy flux $E_{ent} = \rho_0 v_0 R\ \gamma/(\gamma-1)dT/dl$, where v_0.is the velocity deduced from C IV dopplergrams and ρ_0 the corresponding density; dashed line is the power supply deduced from the balance.

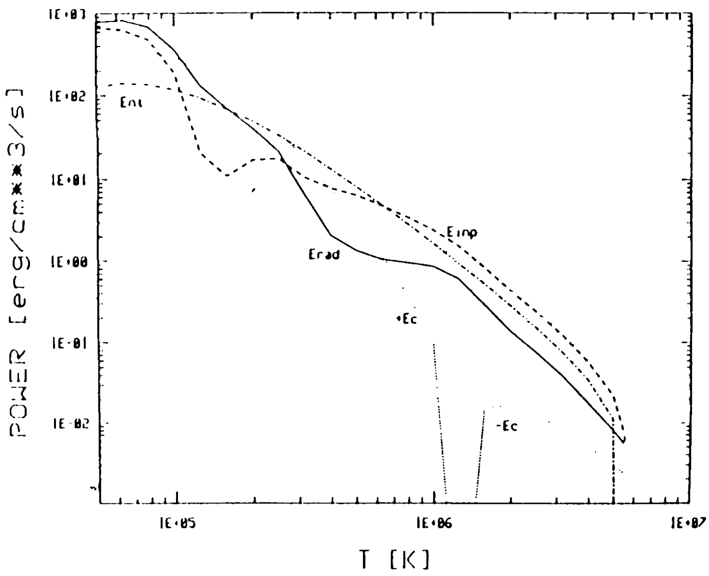

fig.3

Clear indication exists that a power supply is necessary over all the coronal part of the loop (T_c> 10^6 K) where it depends on the temperature with a power law very near to $T^{-2.5}$ (or $n^{2.5}$ due to the costant pressure condition)

3. CONCLUSIONS

Pressure of the order of 10 dyn cm^{-2} and maximum temperature around 5 10^6 ^oK are obtained in this low evolving flare; both temperature and pressure increase during the event: almost twince the pressure and less than 30% the temperature indicating a gradual increase of density (evaporation from the feet??)

Since the time evolution of the temperature is very slow a stationary analysis is performed, the conductive, convective and radiative terms of the energy balance are evaluated and the power supply along the loop is estimated. Over most of the coronal region of the loop a continuos power supply is needed which is not costant and follows approximatly a power low of the temperature about $T^{-2.5}$(or $n^{2.5}$ since pressure is costant).

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