XSST/TRC ROCKET OBSERVATIONS OF 13 JULY 1982 FLARE

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ABSTRACT

We analyse the Ultra-Violet filtergrams of the 13 July 1982 solar flare, taken by the Transition Region Camera, during the third flight of the joint Lockheed/LPSP rocket experiment XSST/TRC. From the calibrated intensities of the flare components, we estimate directly the Lyα line flux (from 230 to 650 \(10^3\) erg cm\(^{-2}\) s\(^{-1}\) sr\(^{-1}\)), differentially the CIV line flux (from 30 to 130 \(10^5\) erg cm\(^{-2}\) s\(^{-1}\) sr\(^{-1}\)), and the excess of 160 nm continuum temperature brightness (from 100 to 250 K) over the underlying plage. No detectable variation is observed in the 220-nm channel formed in the medium photosphere. These values are small compared to other observed or calculated equivalent quantities from Machado model of flare F1.

We estimate the corresponding power required to heat the temperature minimum accordingly over the 1200 Mm\(^2\) area, to be \(3.6 \times 10^{25}\) erg s\(^{-1}\) for this small X-ray C6 flare, 7 minutes after the ground based observed flare maximum.

1. INTRODUCTION

We report on the observations of a solar flare on 13 July 1982, obtained during the third flight of the rocket experiment TRC (developed at the Laboratoire de Physique Stellaire et Planétaire du C.N.R.S.) and XSST (X-ray Spectrometer, Spectrograph and Telescope) developed at the Lockheed Palo Alto Research Laboratory.

The X-ray Preliminary results have been presented in Bruner et al. (1980), and we shall concentrate on the ultraviolet filtergrams of the flare area taken by the Transition Region Camera at Lyα, 160 nm and 220 nm.

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2. INSTRUMENT AND OBSERVATIONS

2.1 The Transition Region Camera

The instrumentation of the TRC has been described by Bonnet et al. (1980). It consists of a 10.6-cm telescope, with selectable broad band interference filters at Ly$\alpha$, 157 nm, 162 nm and 220 nm. The filtergrams are recorded on photographic film Kodak 104. The resolution after the whole instrument, film, analysis chain is equivalent to 1 arcsec.

We showed that the 121 nm filter with bandpass 8.5 nm give a photometric measure of the Ly$\alpha$ flux. Two sets of 160 nm filters were used to obtain differentially the CIV line. As we shall discuss later, the CIV contamination of the continuum in the 13 nm bandwidth of the filter is in the range 10% for the quiet sun, 20% for plages and can dominate during flares.

2.2 Flight Sequence

The flight occurred at White Sands Missile Range on 13 July 1982 at 16:30 UT. The Nike boosted Black Brant rocket reached 300 km. The selectable broad-band interference filters mounted on a 4 position wheel were sequentially introduced into the optical path. A series of five exposure times were programmed and commanded through an electronic sequence, with a range of exposures enabling the correct photographic density on faint quiet areas, intense active regions and over the flaring area.

Before the flight we had agreed to concentrate the observations with simultaneous ground based observers on the larger active region (Sac Peak 6666F). However, 5 minutes prior to launch a flare commenced in another active region/Sac Peak 6668D, and it was decided to point it with the master XSST instrument. The flare was located with the aid of the on board H$\alpha$ telescope and real time television link. Then a systematic bright point search was carried out, using an automatic raster scanning function of the SPARCS pointing system. With the XSST instrument two spectra were taken in the range 12-05 $\AA$ of the brightest area of 2 arcsec by 25 arcsec on the sun. With the TRC camera, we obtained three sequences (at 16°33'08", 16°34'40", 16°36'10" UT) each including a series of 5 exposure times for every filter set (162 nm, 220 nm, 157 nm, Ly$\alpha$), which allowed a time resolution of 1 nm 30 s for the Ly$\alpha$ and 220 nm channels, and of 42 s between 160 nm pictures taken with alternating filters 1 and 3.

2.3 Description of the X-Ray Spectrum of the Flare

The X-ray spectrogram taken simultaneously (Fig.1) covers an interval from 8 $\AA$ to 97 $\AA$ with a spectral resolution of about 0.021 $\AA$ (Bruner et al 1980). The spectra were recorded on Eastman 101 film, and corresponded to a entrance slit covering a field of 25 arcsec by 2 arcsec in the brightest Kernel points of the flare. The observed wavelengths range from 12.13 $\AA$ (Fe XVII/NeX) to the 93.94 $\AA$ line of Fe XVIII. Observed ions include CV, CVI, OVII, OVIII, N VI, N VII, NE VIII-X, Mg VII-X, Si X-XII, S XIII, A XIV, Ca XIII-XV and Fe XIII-
Figure 1. X-ray spectrogram of 1982 July 13 solar flare taken by XSST. Some of the atomic ions are identified on the spectrum. Two exposures of 45 and 154 s are slightly shifted on the photographic film.
Figure 2. H-alpha picture of the flaring region taken at 16:32 UT during the launch. The position of the entrance slit of XSST spectrograph is indicated and corresponds to 25 arcsec height.
The range of ionization equilibrium temperatures extends from \(7 \times 10^7\) K (Ne VIII) to \(7 \times 10^6\) K (Fe XIX). The emission measure diagnostic analysis is described for some of these lines in Acton et al (1983) with a discussion of flare cooling processes in loop structures.

We shall then concentrate on the analysis of the TRC ultra-violet calibrated images of the flare.

3. ANALYSIS OF THE TRC ULTRAVIOLET PICTURES OF THE FLARE

3.1 Flare images in 220 nm, 160 nm and Ly\(\alpha\)

The flare took place in the active region Sac Peak 6666F formed by an elongated group of moderately developed spots, between the large spot and the less evolved spots with a different polarity. The 220 nm picture which investigates the medium photosphere at 200 km shows the geometry of the spots, while a simultaneous magnetogram obtained at Sacramento Peak observatory shows the complex distribution of the magnetic field, with additional concentration of field of opposite polarities between the main spots. In both the 160 nm and Ly\(\alpha\) pictures, the flaring area can be divided in several components: a group of several ribbons of very strong energy dissipation with a total equivalent area of 1200 M\(\text{m}^2\), an extended filament of length 160 Mm and width 15 Mm that appears clearly tilted and locally enhanced in intensity at several points.

The Ly\(\alpha\) flare relative excess is less than for the 160 nm pictures, which suggests a stronger temperature sensitivity of these pictures, in favour of the CIV dominant contribution.

3.2 Statistical parameters of the flare region

3.2a Components in the flaring area

We distinguished from the 160 nm pictures (of Fig. 3) three components in the flaring area: the ejected filament covering an area of 1500 M\(\text{m}^2\) (5.2%), the flaring area covering 1200 M\(\text{m}^2\) (4.1%) and the intense kernels covering the brightest 30 M\(\text{m}^2\) (0.09%) from the 170 Mm x 170 Mm field area isolated for the study of the flare.

The underlying plage area covers 3200 M\(\text{m}^2\) (11%) out of the field area. We indicated the area percentage of the field over which we calculate intensity histograms. The remaining area is covered by the mixture of quiet sun, network and enhanced network around the plage. For these components, we measured the following relative intensities:
Figure 3. Iso Contour image of the 160 nm - F³ calibrated filtergram showing the limits of the components that we distinguished in the flaring area: Underlying plage (20<UP<40), Average flare (40<AF<80), Flare Kernel (80<K<120)
Table 1

<table>
<thead>
<tr>
<th>Component</th>
<th>Filters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>220nm</td>
</tr>
<tr>
<td>B average quiet cell</td>
<td>8</td>
</tr>
<tr>
<td>C average quiet sun</td>
<td>11.6</td>
</tr>
<tr>
<td>UP underlying plage</td>
<td>15</td>
</tr>
<tr>
<td>Fi flare filament</td>
<td>11</td>
</tr>
<tr>
<td>EF extended flare area</td>
<td>15</td>
</tr>
<tr>
<td>FK flare kernel</td>
<td>15</td>
</tr>
</tbody>
</table>

with a RMS accuracy ranging from 10% for the quiet components to 30% for the brightest ones.

We can scale the corresponding solar fluxes by the literature estimates of the average quiet sun C component, corresponding to a brightness temperature of 4200 K at 160 nm and a continuum flux

\[ F_{\text{cont}}^{160} (\text{Quiet Sun}) = 1.06 \times 10^2 \text{ erg cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1} \text{ A}^{-1} \]

3.2b Intensity histograms

The inspection of the intensity histograms (Fig. 4) shows the role of these active plage and flare components in the asymmetry towards higher intensities. The comparison of histograms taken at filters F¹ and F³ shows an additional contribution in the intensity distribution for the filter including more CIV. The 220 nm histogram does not evidence any asymmetry over to the intrinsic medium photosphere variations. There was not any detectable enhancement (with excess more than 30K) over the plage intensity corresponding to the flare components described in 3.2a.

4. INTERPRETATION

4.1 CONTAMINATION BY EMISSION LINES

From the literature (cf Table in Foing & Bonnet 1985), we can estimate the level of line contamination through the bandpass of the TRC filters. The main contributors are CIV, CI and possibly FeII lines. Following (Samain et al 1975) we have mentioned the integrated intensity over the spectral lines for the average quiet sun. Feldman, Doschek (1978) and Doschek et al (1977), Cook and Brueckner (1979) give the corresponding intensities for a plage and a flare. For the average quiet sun the line contamination over the bandpass integrated continuum is expected to be for filter 3, 11% by CIV and 4% by CI. Although the continuum enhancement is of a factor 7-10 in flares, the CIV contribution (due to its higher temperature sensitivity) can contribute for 140-200% of the bandpass continuum in these components.
Fig. 4. Histograms of the brightness temperature distribution with the different filters used by TRC 4 for:

a - a quiet sun area at 165 nm continuum and for an area including a plage and a flaring region;
b - at 165 nm filter excluding C IV line
c - at 155 nm filter including C IV line
d - at Ly alpha filter
e - at 220 nm filter.
4.2 Modelisation of the observed flare excess 160 nm intensities

If we consider now that the measured intensity at 160 nm is composed of a blackbody emission at brightness temperature $T_B$ and of a CIV flux $F_{CIV}$, we have through the filter $i$

$$F_i = \alpha \frac{T^{i\max}}{T^{155\max}} \int_{T^{155\max}}^{T^{i\max}} B_{\lambda}(T_B) \, d\lambda + \frac{T^{155}}{155} F_{CIV}$$

with the filter response $T_i(\lambda)$, maximum response $T^{i\max}_{155}$, FWHM ($\Delta\lambda^i$) and response at 155 nm $T^{155}$ given for filters F$^1$, F$^2$, F$^3$ and F$^4$. The geometrical and efficiency conversion factor between solar surface flux and the luminance on the photographic plate other than filter transmission being $\alpha$.

From the filter responses, and over the range $4000 < T_B < 5500 \text{ K}$ we finally find that the measured contribution from CIV can be estimated by $\alpha 1.8 \times 10^{-1} F_{CIV}^2 F^3 - 1.558 F^4$, and the continuum contribution in filter 1 by

$$\alpha \frac{T^{1\max}}{2} \frac{\Delta\lambda^2}{\Delta\lambda^1} \int_{T^{1\max}}^{2T^2(\lambda)} B_{\lambda}(T_B) \lambda \Delta\lambda^1 = F^1 - 1.38 (F^3 - 1.558 F^4)$$

We then use measurements of the average quiet sun continuum fluxes to scale these continuum and line fluxes in absolute.

Table 2

<table>
<thead>
<tr>
<th>Component</th>
<th>$\Delta T_{220}^B$</th>
<th>$\Delta T_{160}^B$</th>
<th>$F_{160}^{\text{cont}}$</th>
<th>$F_{CIV}$</th>
<th>$F_{Ly\alpha}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>-100</td>
<td>-130</td>
<td>0.56</td>
<td>3.5</td>
<td>50</td>
</tr>
<tr>
<td>C</td>
<td>0</td>
<td>0</td>
<td>1.06</td>
<td>2.75</td>
<td>65</td>
</tr>
<tr>
<td>UP</td>
<td>120</td>
<td>170</td>
<td>2.48</td>
<td>10.2</td>
<td>150</td>
</tr>
<tr>
<td>Fi</td>
<td>0</td>
<td>0</td>
<td>0.4-0.46</td>
<td>24.2-48</td>
<td>160-260</td>
</tr>
<tr>
<td>EF</td>
<td>120</td>
<td>270-360</td>
<td>4.1-6.45</td>
<td>31-80</td>
<td>230-390</td>
</tr>
<tr>
<td>FK</td>
<td>120</td>
<td>360-420</td>
<td>6.45-8.8</td>
<td>80-126</td>
<td>390-650</td>
</tr>
</tbody>
</table>

where the excess temperature continuum brightness at 220 nm and 160 nm, $\Delta T_{220}^B$ and $\Delta T_{160}^B$, are estimated in K over the average quiet sun reference. The continuum flux at 160 nm $F_{160}^{\text{cont}}$ is expressed in $10^2 \text{ erg cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1} \text{ A}^{-1}$ and the line fluxes in CIV and Ly alpha ($F_{CIV}$ and $F_{Ly\alpha}$) are expressed in $10^3 \text{ erg cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$. The flux accuracy is internally equivalent to 20% for quiet components and to 50% for the flare components. The absolute fluxes $F_{160}^{\text{cont}}$ and $F_{Ly\alpha}$ are calibrated from Avrett 1985 for the model C.
4.3 Discussion of the obtained flare fluxes

For the filament component, we deduced by our combination of the F1 and F3 image, a continuum contribution which is in the range, or marginally lower than the background underlying average quiet sun, which implies that the observed flux comes dominantly from the CIV line. This is a consistency check of our CIV flux derivation as such an high altitude component may not be dense and cool enough (i.e. thick enough in 160 nm) to emit significantly in the 160 nm continuum.

For the average flare and kernel component, we deduce both a continuum temperature brightness enhancement, and a stronger relative CIV rise that overcomes the former contribution on our TRC 160 nm images. However, there is not any detectable 220 nm excess over the surrounding non flaring plage component within an accuracy of 30 K: this suggests that for this small flare, the medium photospheric layers where 220 nm radiation is formed were not affected.

If we now compare the line fluxes enhancement in CIV and Lyα, we find that the relative increase of the CIV in flare and kernel underlying plage (3-8-12) is faster than the Lyα increase (1.8-3-4), as expected for the 100000 K CIV pure transition region line.

Our 160 nm continuum and Lyα intensities determination can be compared to the calculations from Machado and Avrett flare models which give for

Model F1: \( T_{B,160} = 4900 \) K and \( F_{Ly\alpha} = 2.8 \times 10^6 \) erg cm\(^{-2}\) s\(^{-1}\) sr\(^{-1}\), and for

Model F2: \( T_{B,160} = 5600 \) K and \( F_{Ly\alpha} = 2.4 \times 10^7 \) erg cm\(^{-2}\) s\(^{-1}\) sr\(^{-1}\).

If we take the reference temperature for the average quiet sun from Avrett's model C' (4470 K) we find \( T_{B,160} \) in the range 4740-4830-4890 K for our observed respective component limits. The Lyα fluxes (0.23-0.39-0.5 \times 10^6 erg cm\(^{-2}\) s\(^{-1}\) sr\(^{-1}\)) also indicate that our observed flare was less active than described by model F1.

5. ENERGY BALANCE

5.1 Heating of the temperature minimum

We consider the increase of the 160 nm temperature brightness over the underlying plage, as the result of the heating of the temperature minimum region by \( \Delta T \) over an optical depth \( \Delta \tau \) at 500 nm. The required energy to account for this heating is approximated by:

\[
E = \pi \Delta L = 4 \pi \sigma T^3 \Delta T \Delta \tau_{500}
\]

where \( T \) is the temperature of reference plage.

For the temperature minimum where 160 nm is formed: \( \tau_{500} = 10^{-4} \), and for the medium photosphere where 220 nm informed: \( \tau_{500} = 13 \times 10^{-4} \), we can then take as a conservative upper limit of \( \Delta \tau_{500} = 13 \times 10^{-4} \) for the heated layer optical width as we did not see evidence of heating in the 220 nm pictures. By assuming a smooth flare heating function between these layers, we use \( \Delta T_{500} = 6 \times 10^{-4} \).

Our estimate for the reference temperature of the underlying plage is taken to 4640 K, and of the average flare vs plage \( \Delta T = 150 \) K. Then:
\[ E_{\text{opt}} = 5.0 \times 10^9 \times \Delta \tau = 3.1 \times 10^6 \text{ erg cm}^{-2} \text{ s}^{-1} \]

with \( \Delta \tau = 6 \times 10^{-4} \)

For the total flaring area A, we then have an estimate of the continuum radiative losses in the temperature minimum.

\[ P = A \ E_{\text{opt}} = 3.6 \times 10^{25} \text{ erg s}^{-1}. \]

This power is indicative of a small flare which does not affect the deep dense photospheric layers. This corresponds to a lower estimate of the flare energy budget, as the other contributions from H\alpha and H Balmer lines, Ly \( \alpha \). Chromospheric CaII and MgII contributions, transition region lines and X-ray fluxes and core filling of photospheric lines have not been included. However, we expect that the global energy budget is dominated by the deeper layers' balance which involve a denser material. Also this estimate refers to the phase of the flare observed by the rocket experiment, 7 minutes after the ground based observed maximum.

CONCLUSION

A series of ultraviolet 1" resolution images of a sample flare event has been taken by the Transition Region Camera on 13 July 1982. The statistical analysis of the flare components on the calibrated filtergrams allowed us to estimate the geometry and contrast of the flare over the underlying plage. We obtained directly the Ly alpha flux, and differentially the CIV flux from two sets of filters displaced in wavelength and including a different CIV line contamination. We deduced also the increase of the 160 nm continuum intensity and the corresponding excess of temperature brightness associated to the heating of the temperature minimum region. No flare decrease was detected on the 220 nm pictures of the medium photosphere. We estimated the power radiated from the integrated optical continuum at the temperature minimum for this phase of the flare observed during the rocket flight.

The detailed evolution of the flare energy balance and geometry will be presented in a subsequent paper and compared to model calculations.

The results obtained so far with the Transition Region Camera, especially in the context of the flare observations, indicate clearly directions of future instrumental developments. Such a filtergram instrument allows a time rate (a few seconds) over a large field of view, very adequate to detect and follow the fast evolution of flare type events. Longer time series than the 5 minutes rocket flight would be necessary to have a complete coverage of the flare dynamics. Obviously, such an instrument on board Spartan and Eureka platforms which are operated over periods long enough to increase the chance of observing flares, will contribute on its own and as a background instrument. Also, the SOT provided it is accompanied by an attach-on Ultraviolet imaging device equipped with the right filters, would make a breakthrough in the area of flare dynamics, but also of the fine structure and geometry of chromospheric and coronal magnetic field, and in waves and dissipation processes at very small scale in the upper atmosphere.
ACKNOWLEDGEMENTS

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References

Bruner et al., 1980, Optical Eng., 19, 433.