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Hard X-ray and gamma-ray observations of an electron dominated event associated with an occulted solar flare

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Abstract. This paper reports hard X-ray (HXR) and gamma-ray (GR) observations of an impulsive electron-dominated event which occurred on 1991 June 30 at $\simeq$ 0256 UT. This event is associated with an optical flare produced in an active region located behind the east solar limb. When observed from the earth's direction, it appears as a moderate HXR/GR burst but still shows significant emission in the 10–100 MeV range. During most of the event, the photon spectrum exhibits a hardening above a break energy of 0.5 MeV and no significant GR line (GRL) emission is detected. When viewed from a largely different direction, this impulsive event corresponds to one of the giant flares observed with ULYSSES. The main results of the present analysis are:

(i) the HXR/GR emission observed from the earth's direction represents only a small fraction of the total X-ray emission; while the unocculted emission below 0.5 MeV is likely produced in the corona at heights greater than 10^4 km the higher energy emission probably originates from thick target interaction on the visible disk;

(ii) although associated with an occulted optical flare, this event exhibits at high energies spectral characteristics similar to what is observed for a disk electron dominated event;

(iii) even if no significant GRL emission is detected, the observations cannot exclude that a $\gtrsim$ 1MeV/nuc ion energy content comparable to the $\gtrsim$ 20 keV electron content is produced in the flare; the comparable energy contents between electrons and ions found for strong GRL flares and for one electron dominated event associated with a disk flare thus also holds for the unocculted part of this event.

Key words: Sun: activity – Sun: corona – Sun: flares – Sun: X-rays, gamma rays

1. Introduction

Hard X-ray (HXR) and gamma-ray (GR) electromagnetic radiation produced by energetic electrons and ions accelerated during solar flares have been extensively observed and analysed during the past two decades (see Chupp 1996 for a review and references therein). It has thus been shown that acceleration of both bremsstrahlung producing electrons (above a few tens of keV) and GR line(GRL) producing ions (1–100 MeV/nuc) is a common feature of solar flares and there is strong evidence that the two particle species are in most events produced simultaneously (e.g. Chupp 1996). A rough correlation has been found between the HXR electron bremsstrahlung fluence and the GRL one down to the sensitivity limit for GRL detection (e.g. Forrest 1983; Vestrand 1988; Vestrand 1991; Cliver et al. 1994). Recent estimates of the total ion energy content above 1 MeV/nuc have furthermore shown that it is comparable to the electron energy content above 20 keV (Ramaty et al. 1995). A strong variability of the bremsstrahlung component compared to the nuclear line component is however observed from one flare to the other (see e.g. Fig. 3 in Miller et al. 1997) and even during a given flare (Chupp et al. 1993; Marschhäuser et al. 1994).

For some HXR/GR events, the bremsstrahlung component from energetic electrons is found to extend above 10 MeV(see e.g. Rieger & Marschhäuser 1990; Vestrand et al. 1991; Pelaez et al. 1992; Vilmer et al. 1994; Rieger et al. 1998; Trottet et al. 1998), sometimes up to a few hundred of MeV (e.g. Akimov et al. 1991; Leikov et al. 1993; Kanbach et al. 1993) thus implying the acceleration of ultra relativistic electrons. The production of this high energy continuum is usually very impulsive (a few seconds to a few tens of seconds) and may occur at any time during a flare (Rieger 1994). These transient events referred to as electron-dominated events (Rieger & Marschhäuser 1990) are characterized by weak or no detectable GRL emission and by hard $\gtrsim$ 1 MeV electron bremsstrahlung spectra (mean value of the spectral index above 1 MeV $\simeq$ -1.84) (Marschhäuser et al. 1994; Rieger et al. 1998). The mean value for several electron dominated events of the spectral index of the continuum

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between 0.3 and 1 MeV ($\simeq$ -2.7) does not however differ significantly from that of other flares (Rieger et al. 1998). Some directivity of the high energy continuum emission (and thus some anisotropy of the emitting electron distributions) has been previously inferred from the tendency of the first observed high energy events to be associated with limb flares. However, the independance upon the position at the Sun of the power law spectral index above 1 MeV (Rieger et al. 1998) shows in fact that the anisotropy of the radiating particles is lower than expected in most calculations (e.g. Dermer & Ramaty 1986; Mandzhavidze & Ramaty 1993 and references therein). The apparent lack or the weak GRL emission in these bursts do not necessarily contradict a simultaneous production of electrons and ions and as discussed in Cliver et al. (1994), these events do not seem to constitute a special class of bursts. A recent analysis by Trottet et al. (1998) has also shown that the near equipartition of energy between electrons and ions found for strong GRL flares (Ramaty et al. 1995) can also hold for an electron dominated event, thus indicating that these bursts may be considered as weak GRL flares. The hardness of the bremsstrahlung emission above 1 MeV may simply reduce the contrast due to GRL lines thus making their detection more difficult.

In this paper, we present the first observations of a high energy ($\geq$ 10 MeV) electron dominated event associated with a behind the limb optical flare for near Earth's instruments. The event has also been detected at X-ray energies by another experiment with a largely different viewing angle allowing to measure the total flare emission. In the following, we have compared the emissions recorded from the earth's direction to the total X-ray emission and investigated the different possibilities for the HXR/GR emitting sites for the emissions seen from the earth's direction. We have also confirmed that this event presents all the spectral characteristics of electron dominated events and examined the time evolution of the spectrum. We have estimated the energy content in electrons as well as a limit of the energy contained in ions for the fraction of the emission detected from the earth's direction.

2. Optical flare location

A solar HXR/GR flare was detected in the $\sim$ 20 keV-90 MeV energy range on June 30 1991 from $\sim$ 0256 UT to $\sim$ 0300 UT by spectrometers aboard Earth orbiting satellites i.e.: by BATSE and EGRET on CGRO/COMPTON (Schwartz et al. 1992; Dingus et al. 1994) and by PHEBUS on GRANAT (Vilmer et al. 1994). A soft X-ray (SXR) flare was also observed by GOES (M5.0) from 0243 to 0320 UT (Solar Geophysical Preliminary and Comprehensive Reports). The GOES time profile reveals a sharp increase of the SXR flux at 0255 UT, i.e. close to the onset time of the present HXR burst. The SXR emission reaches its maximum shortly after 0300 UT. Following indications given in the GOES preliminary listing of solar X-ray flares Vilmer et al. (1994) have associated this HXR/GR event with a Hα flare located at S06W19 in the NOAA active region 6693. However, the occurrence of such a flare was not confirmed in Solar Geophysical Preliminary and Comprehensive reports. Moreover Kane et al. (1995) report that the June 30 1991 HXR event: (i) was also detected above $\sim$ 25 keV by the Gamma Ray Burst (GRB) experiment aboard Ulysses, located at a heliolongitude of $\sim 135^\circ$ east of the Earth–Sun direction (Hurley, private communication) and (ii) is one of the few "giant" HXR flares observed by the GRB experiment with a peak energy flux above 20 keV reaching 6.4 10^{30} erg s^{-1}. On the other hand this HXR event appears as a moderate one, when observed from the Earth's direction (see Sect. 5). This indicates that only a fraction of the emission was detected by Earth orbiting instruments. In agreement with Kane et al. (1995) we thus conclude that, for a terrestrial observer, the June 30 1991 HXR/GR event is most likely associated with an optical flare located behind the east limb of the Sun.

Among the different active regions crossing the east limb shortly after June 30 1991, AR 6703 appears to be the best candidate for the flare site. Indeed, it is a large and complex active region which produced during its transit on the solar disk numerous flares of large optical importance and GOES events of classes X and M. Furthermore, an eruptive loop system, associated with AR 6703, was observed above the east limb shortly after the HXR/GR flare (Solar Geophysical Data Comprehensive Reports). Hα and KIV observations, obtained by the Meudon spectroheliograph between June 30 and July 7 1991 (Z. Mouradian, private communication), provide further support to locate the June 30 1991 flare site within AR6703. Indeed AR6703 appears on the east limb on July 1 1991 and shows a large number of close sunspots in KIV. After July 7 1991 these sunspots disappear and there are no longer GOES flares of class X associated with this region. In Hα this group of sunspots corresponds furthermore to a large and complex active region with sunspots distributed around a twisted magnetic neutral line.

The location of the June 30 1991 flare site within AR6703 was estimated by using the positions of (1) the centroid of the sunspot group, (2) of all the Hα flares producing GOES events and (3) Hα flares associated with GOES events of M and X class, reported in NOAA Solar Geophysical Preliminary and Comprehensive reports, during the transit of this region across the solar disk. A linear least-squares fit and extrapolation of these locations as a function of time lead to the conclusion that the June 30 1991 flare occurred 2° behind the east limb. However, given the large longitudinal extent ($\sim 10^\circ$–20°) and the sunspot configuration of AR 6703 (once completely seen on the visible disk), it cannot be excluded that the flare occurs as far as 12° behind the limb in the trailing edge of the active region. The correspondig occulting height for HXR/GR emissions observed by both PHEBUS and GRO/COMPTON instruments is then in the range of 300–10 000 km above the photosphere.

3. HXR and GR observations with PHEBUS and BATSE

The PHEBUS experiment has been described in (Barat et al. 1988; Barat 1993; Talon et al. 1993). In this study we present results from the analysis of data recorded during the June 30 1991 event by the most brightly illuminated detector. The data discussed below consist of 39 channel spectra in the 0.12–90 MeV energy range recorded from 0255:58 UT (when the onboard system triggered the burst observing mode) till 0300:19 UT (when the 0.12–0.15 MeV count rate has fallen below 3σ above the background). Until 0256:35 UT the spectra are recorded with a variable resolution time in the $\sim$ 0.15–0.6 s range. Afterwards the spectral resolution time is 1 s and 4 s below and above 10 MeV respectively.

A description of the BATSE experiment can be found in Pendleton et al. (1995). The data used in this study consist of 16 channel spectra in the 20 keV–8 MeV energy range, obtained with the large area detectors and recorded with a time accumulation of 2 s from 0255:32 UT till 0257 UT when GRO/COMPTON entered the night for solar observations. The detector pointing most directly at the Sun was not used in the analysis, since at high time resolution pulse pile-up was found at the peak of the flare due to too high photon count rates (see also Park et al., 1997). We thus analysed data from the next closest detector because its peak count-rate was sufficiently low to prevent from pulse pile-up.

Fig. 1 displays the time evolution of the event as observed with BATSE and PHEBUS between 25 keV and 37 MeV. The time profile is relatively smooth at low energies but at higher energies (see the 0.43–0.57 MeV time profile in Fig. 1) well defined flux enhancements are observed at respectively 0256:14 UT, 0256:24 UT and 0256:32 UT. Due to limited count statistics these peaks are not recognized above $\sim$ 0.8 MeV. When recorded and analysed with a high time resolution the $\gtrsim$ 0.1 MeV integral count rate (not plotted here) clearly shows that these flux enhancements are significant with a time accumulation of 0.5 s. Significant emission (at least 3σ above the background) is observed up to 37 MeV from 0256:18 UT to 0256:39 UT.

Spectral analysis of the PHEBUS data was performed for different count spectra which are accumulated over a varying time interval (in the 3–10 s range) from 0255:58 UT till 0256:35 UT and over a fixed time interval of 4 s after 0256:35 UT (see the above remarks concerning the spectral resolution time of PHEBUS). A trial photon spectrum, defined by an analytical expression with a set of free parameters is convolved with the detector response function to build a test count spectrum which is compared to the observed one. A χ^2 minimization algorithm is used to determine the parameters of the test spectrum providing the best fit to the observed count spectrum. From 0256:14 UT till 0257 UT a photon spectrum represented by a double power law with a break energy leads to a reasonable representation of the observed count spectra. With a normalization energy of 0.05 MeV, the free parameters are A (photons $\mathrm{cm^{-2} MeV^{-1} s^{-1}}$) the photon flux at 0.05 MeV, γ_1 the power law index at low energies, E_b the break energy and γ_2 the power law index for $h\nu > E_b$. Between 0256:14 UT and 0257 UT the values of γ_1, E_b and γ_2 remain approximately the same and lie in the following range: $\gamma_1 \simeq 2.8 \pm 0.1$, $E_b \simeq 0.54 \pm 0.2$ MeV and $\gamma_2 \simeq 1.9 \pm 0.2$. It can however be noticed that only one spectrum (from 0256:35 UT to 0256:39 UT) corresponds to the upper limit of the range of the break energy. It also corresponds to the smallest value of the range for γ_2. Before 0256:14UT, the counting rate at high energies is too low for a double power law to be well defined and only a single power law spectrum can be considered. Due to the low count-rate, the power law spectral index is not as well determined as later in the event and we just take the results as an indication that γ_1 lies around 3 ± 0.5. After 0257 UT, in the decay phase of the event, the low energy part of the photon spectrum progressively hardens and the whole spectrum evolves towards a single power law. A value of $\gamma_1 \approx \gamma_2 \approx 2$ is reached around 0257:40 UT, when the > 1 MeV photon flux is no longer significant. Fig. 2 shows that there is no significant excess ($> 3\sigma$) above the expected power law spectrum in the 1–8 MeV energy range around the maximum of the event. This holds for the whole event, even during the decay phase. This indicates that within PHEBUS sensitivity, emission from the prompt GR lines as well as from the 2.23 MeV neutron capture line is not significantly detected during the June 30 1991 flare. While the lack of 2.23 MeV line emission is expected for a behind the limb flare (e.g. Hua & Lingenfelter 1987), the absence of significant prompt GR line emission shows that the June 30 1991 HXR/GR burst belongs to the category of electron-dominated events introduced by Rieger and Marschhäuser (1990).

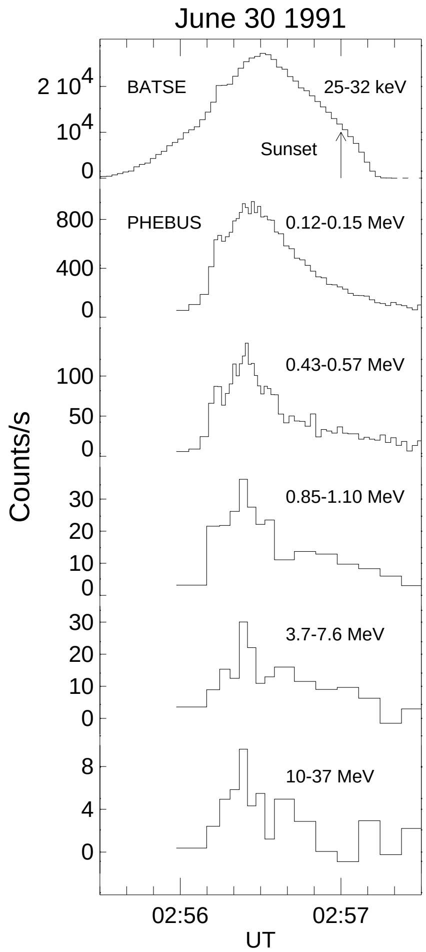

Fig. 1. The time evolution of the HXR/GR background-subtracted count rate recorded by BATSE and PHEBUS in different energy bands. The arrow indicates the time when GRO/COMPTON entered the night for solar observations

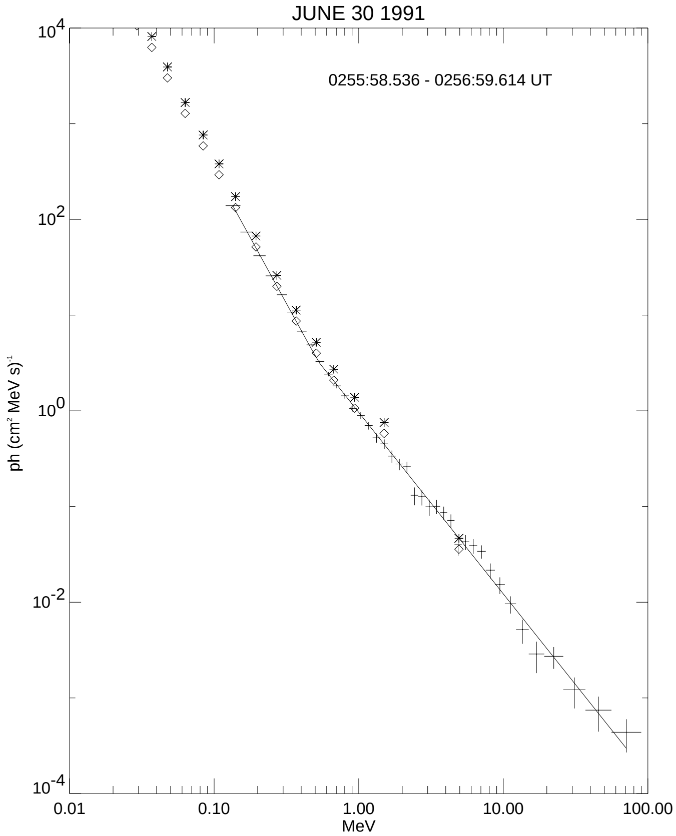

Fig. 2. HXR/GR Photon spectrum observed by PHEBUS between 0255:58.536 and 0256:59.614 UT (error bars). The solid curve represents the best fit double power law photon spectrum. The stars represent the photon spectrum deduced from the spectral analysis of BATSE count-rates in the same time interval. The diamonds represent the same quantities divided by 1.3

A similar analysis was performed for 30 keV-1 MeV BATSE count spectra accumulated over the time intervals used for the PHEBUS analysis. The parameters found between 0256:14 UT and 0257 UT are $\gamma_1 \simeq 2.8 \pm 0.2$, $\gamma_2 \simeq 1.75 \pm 0.15$, $E_b \simeq 0.575 \pm 0.175$ MeV, in good agreement with the values deduced by PHEBUS. Fig. 2 shows the best fit photon spectrum deduced from both experiments for counts accumulated between 0255:58 UT and 0256:59 UT. The solid curve represents the best fit photon spectrum deduced from the PHEBUS observations alone. The crosses correspond to the PHEBUS observed counts converted to photons according to the standard forward-folding technique (Laredo & Epstein 1989). The stars and the diamonds represent respectively the BATSE counts converted to photons and the same quantity divided by 1.3. Fig. 2 shows that the shape of the photon spectrum deduced from PHEBUS is consistent with that deduced from BATSE. It must be noticed that the shape of the photon spectra deduced above 1 MeV independently from PHEBUS and EGRET are also consistent with each other. Indeed Dingus et al. (1994) have shown that the EGRET spectrum is well represented by a power law with $\gamma_2 \approx 1.98 \pm 0.03$. Dingus et al. (1994) also noticed that no significant prompt and 2.23 MeV GR line emission was detected by EGRET. The absolute flux values also agree within 30% between the PHEBUS and BATSE determinations. This difference is of the order of what is usually found when comparing absolute photon fluxes obtained from two different experiments (see e.g. Kane et al. 1982) and does not change the conclusions of the present paper. For the spectrum shown in Fig. 2 we finally obtain a > 50 keV fluence of 3.6 10^3 photons cm^{-2} and bremsstrahlung fluxes above 1 and 10 MeV of resp. 1.1 and 0.14 photons cm^{-2} s^{-1}.

4. Microwave associated emission

Microwave emission is observed at Nobeyama during the whole HXR/GR burst at 17 and 35 GHz. Fig. 3 shows the time evolution of the radio flux density at both frequencies together with the HXR count-rates in 3 energy bands. A small increase is observed around 025550 UT at 17 GHz in the rising phase of the HXR emission and is followed by an intense emission starting around 025605 UT. Three peaks are observed at both 17 and 35 GHz (resp. at 025611 UT, 025620 UT and 025629 UT at 17 GHz, i.e. a few seconds before the HXR flux enhancements in the $\geq$ 0.1 MeV time profile discussed in Sect. 3). The time profile at both frequencies then exhibits a tail with a slow decay from 025640 to about 025730UT. Between the two observing frequencies, the shape of the microwave spectrum has been taken as a power law of the form f^{α}. From 025605 UT to 025622 UT (around the time of the onset of the $>$ 10 MeV peak at a 3σ level), α lies in the [-1,-0.5] interval. It then increases and becomes positive (the microwave emission is clearly optically thick at 17 GHz) during the third peak at 17 and 35 GHz which roughly corresponds to the time of the maximum of the HXR emission at 25–32 keV. After 025632 UT α returns to a negative value and lies again around -0.5 between 025638 UT and 025648 UT. It then increases again slowly up to the end of the microwave emission. The range of values of α indicates that the optical thickness τ at 17 and 35 GHz is close to 1 and that absorption effects may significantly reduce the microwave flux(up to an order of magnitude if τ around 2). Although observations at two frequencies are not sufficient to describe in details the shape of the microwave spectrum, the variation of α also indicates that the optical thickness of the medium evolves with time. Furthermore, when the value of α is negative, the 35 GHz flux can be grossly considered as optically thin and its time variation linked to the one of the energetic electrons in the microwave emitting source. Therefore, we shall consider in the discussion the values of the microwave fluxes in the first two peaks of the event (when α is negative).

5. Discussion

This paper describes the observations of a HXR/GR event associated with a behind-the-limb optical flare. Observed from the Earth's direction this event appears as a moderate HXR burst with a $>$ 50 keV fluence (3.6 10^3 ph cm^{-2}) comparable to fluences observed for many events with HXRBS/SMM (Cliver et al. 1994). The bremsstrahlung fluxes above 1 and 10 MeV are also at least 600 times smaller than what was estimated for a

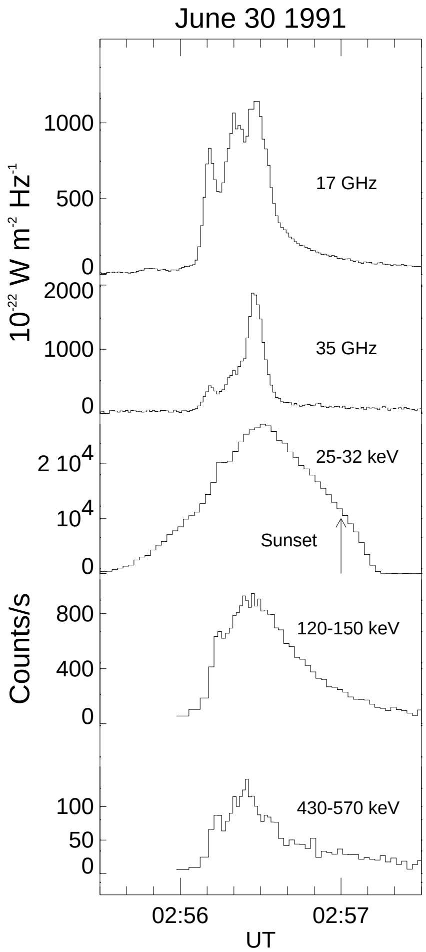

Fig. 3. Comparison of the time evolution of the centimetric–millimetric flux density observed at Nobeyama at 17 GHz and 35 GHz with that of the HXR/GR detected by BATSE and PHEBUS in the 25–32 keV, 120–150 keV and 430–570 keV energy bands

photon spectrum with γ=2 by Ramaty et al. (1994) for the large X12$^+$ flare of June 4 1991. When viewed with a largely different angle by the X-ray experiment aboard ULYSSES, this event of moderate importance corresponds to one of the few "giant" flares reported by Kane et al. (1995).

As seen from the earth, the occulted flare produces a significant $>$ 10 MeV GR emission. HXR/GR bremsstrahlung below 10 MeV, neutron capture line and prompt gamma-ray line have already been observed for behind the limb flares (e.g. Hudson 1978, Kane et al. 1992, Vestrand & Forrest 1994, Barat et al. 1994). Different explanations can be found in the literature:

– the emission may arise from a relatively low density medium located in the low corona at heights above the occulting limit. The emission is then produced as a thin target in a coronal loop either by perfectly trapped particles (e.g. Hudson 1978, Barat et al. 1994) or by particles evolving in a leaky trap with the thick target part of the radiation from the loop footpoints being occulted (e.g. Hulot et al. 1992)
– the emission is a thick target radiation produced on the visible disk because in addition to a compact emitting source located close to the flare site but behind the limb, there is a spatially extended source on the visible disk (Vestrand & Forrest 1994) or because large-scale loop systems in which energetic particles may propagate connect the flare site to the visible disk.

In the present case, there is no strong argument allowing to discard one of the interpretation and a combination of the above cases cannot be excluded. The hardening of the HXR photon spectrum below 0.5 MeV in the decay phase of the event (after 0257 UT) could argue in favor of some trapping effect in a relatively low density source after the end of the energetic particle injection. The HXR spectra computed with the models developed by Vilmer, Kane & Trottet (1982) show indeed that a spectral hardening similar to the one observed in the present event can occur between 100 keV and 500 keV on a time scale of $\simeq$ 30 s if the density in the coronal trap lies in the 10^{10}–10^{11} cm^{-3} range. However, contrary to what was observed for the 1991 June 1 event where the emission is interpreted as thin target emission in a low density loop (Barat et al. 1994, Trottet et al. 1996) the time profile during the whole event does not exhibit any smoothing at higher energies which should be observed in case of trapping at high energies. On the contrary, as discussed in Sect. 3, the time profile is smoother at lower energies (below $\simeq$ 0.5 MeV) than at higher energies. The observed flat photon spectrum at high energies is also an indication that the high energy emission cannot be produced as a thin target since it would imply an unrealistically flat emitting electron distribution. All the observational facts could in fact be explained if several components are observed in such an event: a smooth less energetic component being produced by trapped electrons in a large coronal source and a more impulsive emission emitted when some high energy electrons impinge on the magnetic footpoints of loops located on the visible disk. In such a case, the observed hardening of the photon spectrum at low energies in the decay phase would simply trace the evolution of the electrons trapped in the coronal source.

As discussed above, the X-ray emission below 0.5 MeV observed by PHEBUS and BATSE is either entirely produced through thin target interaction as in some other occulted HXR flares (Vilmer et al. 1982, Hulot et al. 1992, Barat et al. 1994, Trottet et al. 1996), or through a combination of thin and thick target emissions arising from different emitting sites (as in a trap plus precipitation model, see e.g. Trottet & Vilmer, 1983)). Two extreme limits of the number of electrons necessary to produce the observed HXR emission can be deduced in thin and thick target approximations. Using only the low energy part of the photon spectrum and thin target calculation by Brown (1971), the total energy content E in $>$ 20 keV electrons can be estimated as a function of the coronal density in the emitting source. For a density in the 10^{10}–10^{11} cm^{-3} range consistent with the observed hardening of the spectrum after 0257 UT (see above), E is found to be around 2 10^{28}–2 10^{27} ergs. If compared to the energy input rate deduced by Kane et al. (1995) for the whole flare emission observed by ULYSSES (of the order of 6.4 10^{30} ergs s^{-1}), the total energy content E corresponds to the total flare energy injected over an unrealistically small time of 3 10^{-2}- 3 10^{-3} seconds. This leads to the conclusion, that even if the emission observed by BATSE and PHEBUS is produced through thin target emission, it corresponds only to a small fraction of the total flare energy released. To go further in the comparison of the energetics of the flare observed from the earth's direction and by ULYSSES, it is now assumed that the emission observed by PHEBUS and BATSE is produced through thick target interaction. Considering only the low energy part of the spectrum, the energy input rate for electrons above 20 keV (F) is found to be around 7 10^{27} erg s^{-1} (4 10^{29} erg over 60 s) i.e. about 1000 times less than what is roughly estimated from the unocculted observations of ULYSSES. Under the very rough approximation that occulted and unocculted X-ray spectra have similar spectral slopes, this ratio R of non-thermal energy input rate can be tentatively compared to the ratio of X-ray fluxes at 100 or 150 keV published for previous stereoscopic observations (Kane, 1983, Kane et al. 1992). For the present observations, R is found to be of the order of 10^{-3}. For this rather impulsive flare, such a value is more consistent with the results of published observations in the case of a large occulting height (i.e. of the order or greater than 10^4 km corresponding to the upper limit found in Sect. 2). In conclusion, the rough comparison performed above, using either a thin or thick target approximation for the X-ray emission, leads to the conclusion that, while the total flare was observed at low energies with the X-ray detector aboard ULYSSES, only a very small fraction of the emission was observed by PHEBUS and BATSE. A similar conclusion of a large occultation of the flare as seen from the earth's direction can be inferred from the microwave observations. Indeed, the observed value of the 17 GHz flux (Fig. 3) lies in a moderate range of values when considering the distribution of bursts at 17 GHz as a function of their peak intensity (Kosugi, 1985). Although the frequency turnover of the microwave spectrum is not accurately known, the moderate value of the microwave flux most probably indicates that the microwave emission is related to the part of the flare seen with PHEBUS and BATSE and not to the total "giant" flare observed by Ulysses. In such a case, the flux should be 1 to 2 orders of magnitude larger and comparable to the microwave/millimeter flux observed for the $X12^+$ flares of 1991 June 4 (Ramaty et al. 1994) or June 6 (Kane et al. 1995).

The spectral analysis of the June 30 1991 event reported in Sect. 2 confirms earlier suggestions made by Vilmer et al.(1994) that the spectral characteristics are similar to the ones obtained by Rieger & Marschhäuser (1990) for electron-dominated events: the HXR/GR spectrum extends beyond 10 MeV without any significant GRL line detection. Trottet et al. (1998) suggested from the detailed examination of another electron dominated event that the near equipartition in energy between electrons and ions found for strong GRL flares (Ramaty et al. 1995) may also hold for electron dominated events. In the present case, an ion energy content above 1 MeV/nuc around 4 10^{29} ergs comparable to the electron content deduced from BATSE and PHEBUS would produce a 4- 7 MeV GRL fluence of the order of 2 photons cm^{-2} in the following conditions: the thick target yield is taken from Ramaty et al. (1993), the spectral index for the proton spectrum is taken as -4 and the compositions for both ambient and interacting elements are chosen as the ones deduced from the observations of the April 27 1981 event (Murphy et al. 1991). This estimate of the 4–7 MeV fluence is consistent with the lack of detection (less than 3σ above the continuum) of GRL lines by PHEBUS. It is also around 2 orders of magnitude smaller than the total 4–7 MeV fluence observed by PHEBUS for the coronal emission of the June 1 1991 event associated with an occulted optical flare (Barat et al., 1994, Trottet et al., 1996). However, the total duration of this last event is of the order of 20 minutes compared to $\simeq$ 1 minute in the present case. Under these conditions, the following conclusions can be reached:

- The lack of detectable gamma-ray lines in the case of the June 30 1991 event cannot be attributed to the occultation of the optical flare since it has been shown that strong thin target coronal gamma-ray line emission can be produced at heights between 3000 to 7000 km above the photosphere (Barat et al., 1994, Trottet et al., 1996) with fluxes in the 4–7 MeV range of 0.16 ph cm^{-2} s^{-1} at the maximum and of 7 10^{-2} ph cm^{-2} s^{-1} averaged on the event. It can be noticed that this last quantity is of the same order of magnitude as the upper limit for the June 30 1991 event.
- The main difference lies in the hardest continuum spectrum above 1 MeV for the June 30 1991 event. Under these conditions, although the bremsstrahlung flux of the June 30 1991 event represents above 1 MeV twice the one of the June 1 1991 event, it is in comparison more than 10 times larger above 10 MeV. The detection of prompt lines above the continuum thus requires a more intense gamma-ray line emission compared to the continuum emission. The non-detection of neutron capture line is also not an argument for the lack of production of energetic protons in this flare, since the 2.23 MeV line is known to be strongly attenuated for flares at the limb (e.g. Hua and Lingenfelter, 1987). The above discussion shows that a significant production of energetic ions cannot be excluded in the flare, even if the event presents all the characteristics of an electron-dominated event.

Although associated with a behind-the-limb optical flare, the spectral characteristics above 500 keV of the June 30 1991 event are similar to the ones observed for another electron dominated event which is associated with a disk M4.5 flare (Trottet et al. 1998): a similar spectral shape as well as bremsstrahlung fluxes above 1 and 10 MeV. This may confirm that the high energy part of the emission is in fact produced through thick target interaction on the visible disk from high energy particles accelerated at the flare site and propagating in large coronal loops. The spectral hardening of the photon spectrum above 500 keV is also similar to the behaviour reported above 300 keV in a few events observed by SMM, HINOTORI and YOHKOH (see e.g. Dennis 1988, Marschhäuser et al. 1994, Yoshimori 1989, Yoshimori et al. 1994). A few events observed by EGRET and BATSE or by PHEBUS/GRANAT with a photon spectrum extending up to 10 or 100 MeV also exhibit a clear hardening of the photon spectrum at high energies (Barat et al., 1994, Dingus et al. 1994, Trottet et al. 1998). Although such a spectral hardening at high energies has been considered as one of the characteristics of the electron dominated events (Marschhäuser et al. 1994, Rieger et al. 1998), it must be noticed that it is not limited to these events since the GRL line event observed by PHEBUS/GRANAT and reported by Barat et al. (1994) also exhibits such a flattening. It was shown that the flattening is generally too large to be only attributed to relativistic effects and to the contribution of electron-electron bremsstrahlung (see e.g. the computations by Skibo (1993) presented in Ramaty et al. 1993). The spectral information by itself is however not sufficient to discriminate between the different interpretations proposed in the literature (see e.g. Park et al., 1997): particle transport effects, results of the acceleration mechanism itself or a combination of both effects.

6. Conclusion

This paper presents the first observations of a high energy electron dominated event associated with an occulted optical flare. While the PHEBUS and BATSE experiments only recorded a small fraction of the HXR/GR emission, the GRB experiment aboard ULYSSES provided measurements of the bulk of the flare HXR emission. The main results of this study are summarized below:

1. The fraction of observed emission indicates that the occulting height for near earth's experiments must be of a few 10^4 km above the photosphere. The emission at energies below $\simeq 0.5$ MeV observed from the earth's direction is most probably produced at heights greater than 10^4 km while the higher energy emission results from thick-target interaction of a fraction of higher energy particles leaking from the coronal trap (as in the trap plus precipitation models developed by Vilmer et al. (1982) and Trottet & Vilmer (1983, 1984)) and/or directly injected in large magnetic loops connecting the flare site to an interaction site on the visible disk. However, in the absence of imaging observations of the continuum up to a few hundred keV (i.e. below and above the spectral break) there is no way to prove such interpretations.
2. The June 30 1991 event belongs to the category of electron-dominated bursts. The spectral hardening of the HXR/GR spectrum above 0.5 MeV, systematically observed during the maximum phase of the event may result from transport effects and/or to the acceleration mechanism itself. Although occurring in a different context, this event exhibits spectral characteristics at energies above 0.5 MeV similar to what is observed for a disk electron dominated event (see Trottet et al. 1998), supporting the interpretation that the high energy emission is produced through thick target emission on the visible disk.
3. For this electron-dominated event, a $\gtrsim$ 1MeV/nuc ion energy content comparable to the $\gtrsim 20$ keV electron energy content deduced for the unocculted part of the emission would be consistent with the lack of detection of GRL lines. Therefore, the near equipartition in energy between electrons and ions found for strong GRL flares (Ramaty et al. 1995) and also suggested for one electron-dominated event (Trottet et al. 1998) associated with a disk flare seems also to hold for this electron-dominated event for which only the unocculted part of the emission can be analysed at all photon energies. This implies that in addition to the acceleration mechanisms which should produce non thermal electrons and ions with similar energy contents (see above), particle transport in large magnetic loops does not strongly modify their relative values.

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