COMPTEL OBSERVATIONS OF SOLAR FLARE GAMMA-RAYS

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ABSTRACT

The imaging γ-ray telescope COMPTEL on board NASA's *Compton Gamma-Ray Obserrvatory* has observed a number of solar flares during its first year in orbit. Of particular interest were those X-class flares associated with active region 6659 which took place on June 9, 11 and 15, 1991. COMPTEL is capable of observing solar flares both in its imaging mode (covering an energy range of 0.8-30 MeV) and in its burst mode (covering the energy range 0.1 to 10 MeV). Here we shall summarize the major results from COMPTEL regarding the γ-ray emission from these flares.

INTRODUCTION

The COMPTEL instrument on *CGRO* is a powerful tool for studying both the photon and neutron emissions from energetic solar flares /1,2/. It operates in an energy range which covers that of the nuclear line emissions which are known to be produced in solar flares. With a fairly large FOV (±30°), COMPTEL is often capable of observing the sun even at times when the sun is not the primary *CGRO* target.

In the so-called telescope (or 'double-scatter') mode, COMPTEL collects information on those events which scatter from an upper (D1) detector into a lower (D2) detector. A time-of-flight measurement not only allows for the discrimination between upward and downward moving events, but it also permits the separation of γ-rays from neutrons. Further neutron discrimination comes from pulse-shape measurements in the D1 detectors; this serves to distinguish between events involving electron energy loss (such as Compton scattered γ-rays) and events involving proton energy loss (such as np scattering of neutrons). The COMPTEL telescope mode is normally set up to optimize data collection for non-solar celestial targets. This routine can, however, be interrupted by a BATSE solar flare trigger. When this happens, the telescope mode of COMPTEL is re-adjusted to give neutron events a higher priority in the data collection. This 'solar neutron mode' takes full advantage of the neutron-detection capabilities of COMPTEL by optimizing the use of the limited telemetry rate (~20 events/sec). This limitation has resulted in severe dead-time losses during some of the more intense transient events observed by COMPTEL /3/.

In parallel with the telescope mode, the COMPTEL burst mode continually integrates γ-ray spectra from two D2 detector modules. One of these modules operates in a low energy range (0.1-1.0 MeV), while another module operates in the high energy range (1-10 MeV). The Burst Spectrum Analyzer (BSA) continually integrates spectra from these two modules in a background mode at a programmable integration time (nominally, 100 seconds). Upon receipt of a burst (or solar flare) trigger from BATSE, the BSA goes into a burst mode whereupon it collects a series of 'burst' spectra (typically, 0.1 second integration) followed by a series of 'tail' spectra (nominal 12 second integration time). For solar flare studies, these data complement those obtained in the telescope mode.

THE OBSERVATIONS

From the standpoint of solar physics, the first year of *CGRO* orbital operations was dominated by events in early June, 1991. A target-of-opportunity (ToO) was declared on June 8th due to an unusually high level of activity exhibited by active region 6659. The spacecraft was then re-oriented so that the Sun would be within 15 degrees of the spacecraft z-axis for several days. This ToO period lasted until June 15, when AR 6659 neared the solar limb. In order to maximize the chances of collecting good flare data, the COMPTEL instrument was re-configured into its solar flare mode throughout this period. In this way, COMPTEL was not dependent on a BATSE solar flare trigger to enter its solar flare mode. The detector thresholds were set at 75 keV in D1 and 500 keV in D2, giving a telescope energy threshold of 625 keV. Unfortunately, not all of COMPTEL's detectors were operating at this time. Because of continuing outgassing effects, two of the D2 detectors were off during the ToO. One of these was the low-range burst module; hence, only the high-range (1-10 MeV) burst data is available.

During this target-of-opportunity period, AR 6659 was very active. Not only did it produce several C- and M-class flares, but there were also three X-class flares observed within the COMPTEL field-of-view (FOV). Two of these (those on June 9 and 11) were observed during their impulsive phase, both having occured shortly after orbital sunrise. The third (that of June 15) was observed only during the post-impulsive phase, with observations starting 50 minutes after the onset of the flare.

Figure 1 demonstrates the capability of COMPTEL for imaging celestial photons. Here are shown images of the June 9th and June 15th flares using telescope data collected in the 1-10 MeV interval. Although the solar disk is not resolved in these images, the motion of the sun during this interval is clearly seen. These images also demonstrate one important facet of the Compton telescope - the ability to select individual photons which arrive from a particular direction on the sky. This capability permits us to compile a spectrum which is relatively immune to the effects of partial energy loss in the D2 detectors (a nearly-diagonal spectral response).

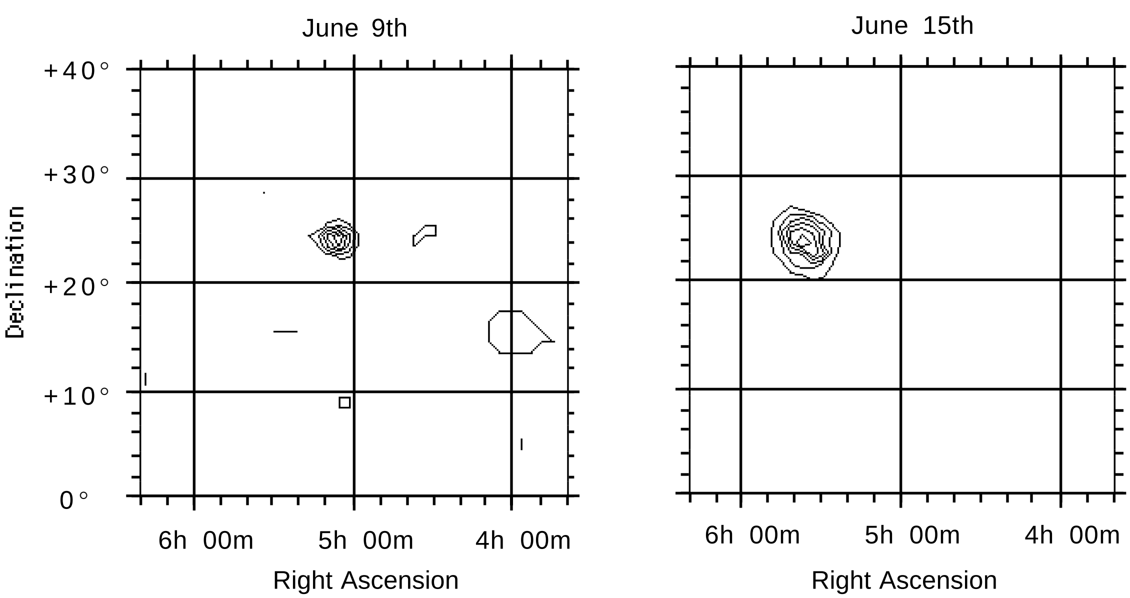

Fig. 1. COMPTEL images of the solar flares on June 9th (left) and on June 15th (right) in the energy interval 1-10 MeV. Compiled from telescope event data, these images clearly depict the motion of the sun during the intervening time interval.

THE RESULTS

June 9th flare. This event was classified as an X10 GOES event starting at 1:34 UT, reaching an X-ray maximum at 1:43 UT and "ending" at 1:52 UT. This flare took place shortly after orbital sunrise, so COMPTEL was ideally situated to study the emissions throughout the entire course of this event. Figure 2 shows the time history of this event in the 1-10 MeV range as compiled from the COMPTEL high-range burst detector. (Note that the broad excess extending from ~ 1:45 UT to ~ 2:05 UT is not associated with the flare, but, rather, orbital variations in the detector background.) The background-subtracted energy spectrum as derived from the telescope data is shown in Figure 3. This includes only those events which are consistent with the solar position (i.e., only those events whose 'event circle' passes within 5° of the solar position). Background data are selected by averaging data collected ±15 orbits relative to the flare; this provides a good reproduction of the geophysical parameters (rigidity, spacecraft orientation, etc.) which most strongly affect the orbital background. The 2.2 MeV deuterium line is clearly seen in this spectrum; its width is consistent with the COMPTEL energy resolution (~8% FWHM at 1 MeV). Other candidate lines (e.g., at 1.6 MeV) also appear to be present. There are only a very few events detected above 7 MeV.

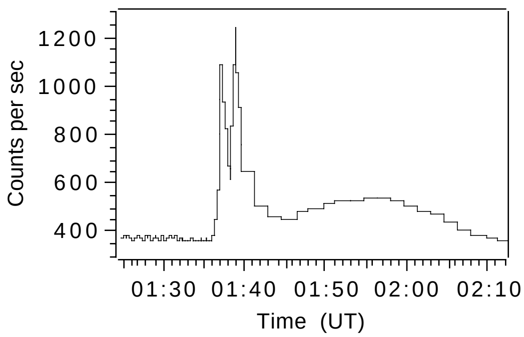

Fig. 2. The time history of the June 9th solar flare as derived from the high range COMPTEL burst data (1-10 MeV).

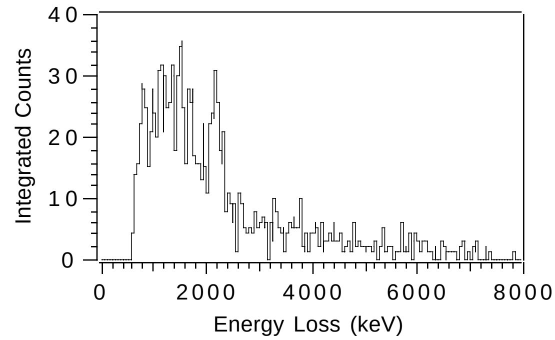

Fig. 3. The background-subtracted energy loss spectrum of COMPTEL telescope events for the impulsive phase of the June 9th flare. The bin size is 40 keV.

<u>June 11th flare</u>. This event was classified as an X12 GOES event starting at 1:56 UT, reaching an X-ray maximum at 2:09 UT and "ending" at 2:20 UT. The orbital sunrise of *CGRO* took place at 1:49 UT, shortly before the onset of the impulsive phase. As with the June 9th flare, COMPTEL was well-placed for observing this event. The time history as measured by the COMPTEL high-range burst detector (1-10 MeV) is shown in Figure 4. The background-subtracted energy spectrum as derived from the telescope data is shown in Figure 5.

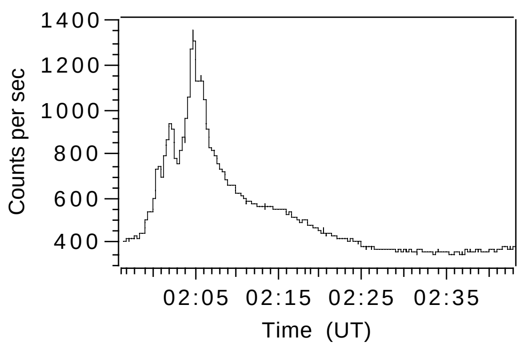

Fig. 4. The time history of the June 11th solar flare as derived from the high range COMPTEL burst data (1-10 MeV).

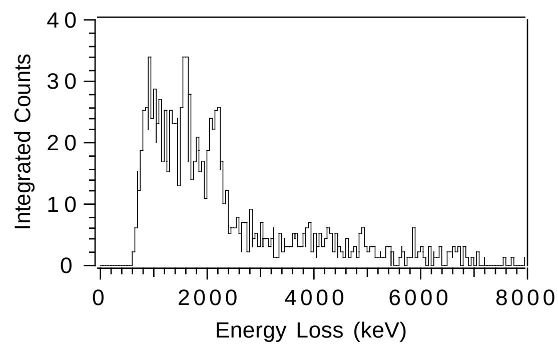

Fig. 5. The background-subtracted energy loss spectrum of COMPTEL telescope events for the impulsive phase of the June 11th flare. The bin size is 40 keV.

The unique feature of this event was the observation, reported by the EGRET team, of emission up to ~1 GeV lasting for several hours after the impulsive phase of the flare /4/. An analysis of COMPTEL data shows that there is also an extended phase of MeV γ-radiation lasting for at least 3-4 hours after the onset of the impulsive phase. This extended emission appears to be dominated by 2.2 MeV line emission. In Figure 6 we show the time history of the event as measured by COMPTEL telescope data in the 2.0-2.5 MeV energy band. The first two data points refer to data collected during the same orbital pass as the impulsive phase. The last data point is integrated over a full orbital pass which took place two orbits later. In the period up until ~4:00 UT, the time constant of the decay was ~21 minutes.

June 15th Flare. This event was classified as an X12 GOES event starting at 8:10 UT, reaching an X-ray maximum at 8:21 UT and "ending" at 14:02 UT. This flare is peculiar in that the impulsive phase was not seen by COMPTEL, having taken place during orbital darkness. At orbital sunrise, the spacecraft was traversing the SAA. So COMPTEL did not begin collecting data on the sun until ~9:00 UT, some 50 minutes after the start of the event. Nonetheless, photon emission in the 1-10 MeV range was seen by COMPTEL for the next 40 minutes (until orbital sunset). The time history of the observed photon emission is shown in Figure 7; the data are crudely fit by a single exponential with a decay time of 13.9 minutes. Observations by the GAMMA-1 experiment /5/ showed emission extending up to 1 GeV in a time period just prior to the start of the COMPTEL observation window.

The COMPTEL data suggest that nuclear line emission persists throughout the course of the 40 minute observation. This implies that accelerated protons are interacting with photospheric material for up to 90 minutes after the impulsive phase. An extensive Hα loop structure was observed to be associated with this active region at the time of the flare. This may suggest the possibility of some type of magnetic storage mechanism.

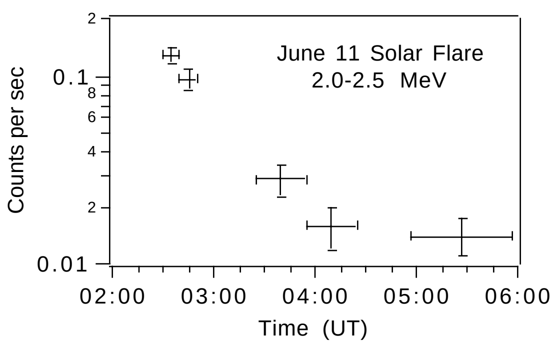

Fig. 6. The observed time history of the 2.0-2.5 MeV energy band during the post-impulsive phase of the June 11 solar flare. These data cover three consecutive orbits.

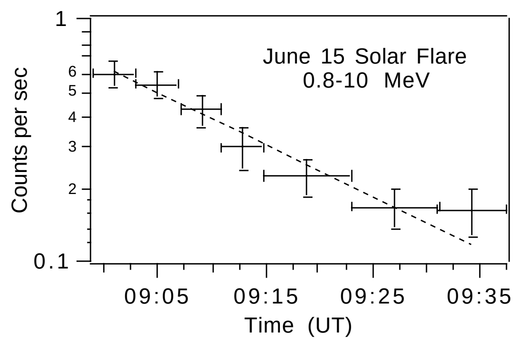

Fig. 7. Time history of the MeV emission from the June 15th solar flare. The dotted line represents a decay time of 13.9 minutes.

SUMMARY

The most striking feature of the June flare data is that two of the three X-class flares observed by COMPTEL (i.e., those on June 11 and June 15) show a very extended post-impulsive phase. This emission lasts up to several hours after the impulsive phase of the flare. The data of June 15 show an extended phase of what appears to be nuclear line emission. The June 11th flare, on the other hand, exhibits an extended phase which is dominated by 2.2 MeV line emission. Both events suggest either a very long acceleration phase or else some type of magnetic confinement of the accelerated particles with a subsequent slow loss into the photosphere. Although the analysis of these data is still in progress, it is clear that the *CGRO* and, in particular, the COMPTEL observations of AR 6659 should allow us to gain unique insights into the acceleration processes taking place in solar flares.

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