X- and gamma-ray observations of the 15 November 1991 Solar Flare

M B. Arndt
University of New Hampshire - Main Campus

A Connors
University of New Hampshire - Main Campus

J Lockwood
University of New Hampshire - Main Campus

Mark L. McConnell
University of New Hampshire - Main Campus, mark.mcconnell@unh.edu

R Suleiman
University of New Hampshire - Main Campus

Follow this and additional works at: https://scholars.unh.edu/ssc

Part of the Astrophysics and Astronomy Commons

Recommended Citation
X- and gamma-ray observations of the 15 November 1991 Solar Flare
M. B. Arndt, A. Connors, J. Lockwood, M. McConnell, R. Suleiman, J. Ryan, C. A. Young, G. Rank, V. Schönfelder, H. Debrunner, K. Bennett, O. Williams, and C. Winkler

Citation: AIP Conference Proceedings 587, 618 (2001); doi: 10.1063/1.1419473
View online: http://dx.doi.org/10.1063/1.1419473
View Table of Contents: http://scitation.aip.org/content/aip/proceeding/aipcp/587?ver=pdftcov
Published by the AIP Publishing

Articles you may be interested in
Expected gamma-ray fluxes from interactions of flare energetic particles with solar wind matter

Solar gamma-ray physics comes of age
AIP Conf. Proc. 587, 603 (2001); 10.1063/1.1419471

CGRO observations of gamma-ray flares associated with ACE particle events
AIP Conf. Proc. 528, 185 (2000); 10.1063/1.1324309

Gamma ray measurements of the 1991 November 15 solar flare

Energetic proton spectra in the 11 June 1991 solar flare
X- and Gamma-Ray Observations of the 15 November 1991 Solar Flare

M. B. Arndt¹, A. Connors¹, J. Lockwood¹, M. McConnell¹, R. Suleiman¹, J. Ryan¹, C.A. Young¹, G. Rank², V. Schönfelder², H. Debrunner³, K. Bennett⁴, O. Williams⁴, and C. Winkler⁴

¹University of New Hampshire, ²Max Plank Inst für Extraterrestrische Physik, ³Univ. Bern ⁴SSD/ESTEC

Abstract. This work expands the current understanding of the 15 November 1991 Solar Flare. The flare was a well observed event in radio to gamma-rays and is the first flare to be extensively studied with the benefit of detailed soft and hard X-ray images. In this work, we add data from all four instruments on the Compton Gamma Ray Observatory. Using these data we determined that the accelerated electron spectrum above 170 keV is best fit with a power law with a spectral index of -4.6, while the accelerated proton spectrum above 0.6 MeV is fit with a power law of spectral index -4.5. From this we computed lower limits for the energy content of these particles of ~10²³ ergs (electrons) and ~10²⁷ ergs (ions above 0.6 MeV). These particles do not have enough energy to produce the white-light emission observed from this event. We computed a time constant of 26±5 s for the 2.223 MeV neutron capture line, which is consistent at the 2σ level with the lowest values of ~70 s found for other flares. The mechanism for this short capture time may be better understood after analyses of high energy EGRET data that show potential evidence for pion emission near ~100 MeV.

INTRODUCTION

The goals of this dissertation work were to add to the extant body of knowledge of the 15 November 1991 solar flare in two ways: by analyzing high-energy data from the Compton Gamma Ray Observatory (CGRO) that have been underutilized in previous studies and by applying another flare model to explain the most intense high-energy emission from the event. In these proceedings we only have space to discuss the CGRO data and analyses.

This X1.5 event was a well observed flare in a broad range of wavelengths [1-26] and is the first to be extensively studied with the benefit of detailed X-ray images. This flare was located near disk center and lasted on the order of minutes in X-rays.

DATA ANALYSIS

COMPTEL data analysis was done using the Maximum Entropy Method (MEM). In this method, a test photon spectrum is folded through an instrument response and
compared to the measured count spectrum using a $\chi^2$ test. EGRET photon spectra were also generated by a MEM approach.

BATSE data were fit with a double power law where $E_B$ is the break energy:

$$I(E) = \begin{cases} E^{-\gamma_1} & \text{for } E < E_B \\ E^{-\gamma_2} & \text{for } E > E_B \end{cases}$$

### RESULTS

Figure 1 is a composite spectrum from the impulsive phase (22:36:36 – 22:38:14 UT) of the flare. All data are background subtracted. The BATSE curve (0.2 – 10 MeV) is an extrapolated fit where $\gamma_2 = -3.6$. The discrepancy between COMPTEL (0.6 – 10 MeV) and EGRET (1 – 300 MeV) spectra near 10 MeV and the emission near 60 MeV are most likely due to background subtraction issues with EGRET data.

**FIGURE 1.** Composite Spectrum of the impulsive phase of the 15 November 1991 solar flare.

**Accelerated Protons**

Using fluences derived from COMPTEL spectra we are able to deduce the shape of the accelerated proton spectrum. Two accelerated proton spectra shapes are considered: the Bessel function, parameterized by $\alpha T$ and the power law, parameterized by $s$. Our values (bold) and previously published values of $\alpha T$ and $s$ [27-29] are listed in Table 1 along with fluence ratios derived from several high-energy emission lines.
The proton spectrum above 0.6 MeV is best fit with a power law of \( s = -4.5 \). The energy content of these ions is \(~10^{27} \text{ ergs}\). These particles do not have enough energy to produce the observed white light emission, which has an energy content on the order of \( 10^{30} \text{ ergs}\).[6]

**TABLE 1. Shape of accelerated proton spectra.**

<table>
<thead>
<tr>
<th>Fluence Line Ratio</th>
<th>Value</th>
<th>( \alpha T )</th>
<th>( s )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \phi_{4d}/\phi_{0d} )</td>
<td>0.035 - 0.065[13]</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>( \phi_{4d}/\phi_{0.223} )</td>
<td>0.52 ± 0.14</td>
<td>0.009±0.002[11-12]</td>
<td>4.5-5</td>
</tr>
<tr>
<td>( \phi_{4d}/\phi_{0.223} )</td>
<td>1.6 ± 0.34</td>
<td>0.008 - 0.015</td>
<td>4-5</td>
</tr>
<tr>
<td>( \phi_{0.7}/\phi_{0.223} )</td>
<td>--</td>
<td>0.010 ± 0.002[25]</td>
<td>4-5</td>
</tr>
<tr>
<td>( \phi_{4.4}/\phi_{0.133} )</td>
<td>2.11 ± 0.47</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>( \phi_{0.33}/\phi_{0.133} )</td>
<td>4.95 ± 1.0</td>
<td>--</td>
<td>4.5-5.5</td>
</tr>
</tbody>
</table>

**2.223 MeV Emission**

Using emission between 3.956 and 7.055 MeV as a template for the neutron production rate \( S(t') \), we compute the 2.223 MeV time constant \( \tau \) using the expression

\[
F_{2.223MeV}(t) = \int_{t'}^{\infty} S(t') e^{-(t-t')/\tau} dt'.
\]

This time constant \( \tau \) is a function of the neutron decay time as well as proton and \( ^3\text{He} \) neutron capture times. Subsequently, \( \tau \) can provide information about proton and \( ^3\text{He} \) densities. We found the best fit to be \( 26 \pm 15 \text{ s} \), which is consistent at the 2\( \sigma \) level with values of \(~70 \text{ s} \) found for other flares.

A low value of \( \tau \) suggests the presence of either an unusually high \( ^3\text{He} \) abundance or that neutron capture is occurring in a dense environment where neutrons thermalize and are quickly captured on \( ^1\text{H} \).

Given our \( \tau \) and a typical chromospheric density, we find a \( ^3\text{He}/\text{H} \) abundance ratio nearly an order of magnitude higher than values computed for other flares, but in agreement with recent results [30].

The white light emission from this flare suggests that very high energy protons are penetrating into the photosphere. The neutrons created in this dense layer would be captured quickly, also resulting in a low \( \tau \).

**Accelerated Electrons**

Table 2 is a summary of spectral indices from various instruments. Included are satellite viewing angles, power law spectral indices below (\( \gamma_1 \)) and above (\( \gamma_2 \)) break energies. If error bars are not included, they were not present in the literature. The data do not all agree within error bars, however the discrepancies may be explained by the different viewing angles of each instrument. We use the indices derived from BATSE data in our work. The energy content (lower limit) from electrons above 170 keV is \(~10^{23} \text{ ergs}\).
TABLE 2. Spectral Indices of Accelerated Electrons During Impulsive Phase.

<table>
<thead>
<tr>
<th>Satellite (Viewing Angle)</th>
<th>$\gamma_1$</th>
<th>$E_B$ (KeV)</th>
<th>$\gamma_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>BATSE (-20°)</td>
<td>2.66 ± 0.27</td>
<td>168 ± 51</td>
<td>3.61 ± 0.23</td>
</tr>
<tr>
<td>OSSE (-20°)</td>
<td>3.0 ± 0.7</td>
<td>100</td>
<td>--</td>
</tr>
<tr>
<td>Yohkoh (-20°)</td>
<td>2 - 4.5[19]</td>
<td>93</td>
<td>--</td>
</tr>
<tr>
<td>PVO (-52°)</td>
<td>--</td>
<td>150</td>
<td>3.37 ± 0.05[15]</td>
</tr>
<tr>
<td>Ulysses (-80°)</td>
<td>3.08[8]</td>
<td>166($\gamma_1$), 150 ($\gamma_2$)</td>
<td>2.72 ± 0.07[15]</td>
</tr>
<tr>
<td>Yohkoh (HXS)</td>
<td>3.20[8]</td>
<td>87</td>
<td>3.82[2]</td>
</tr>
<tr>
<td>Yohkoh (HXT)</td>
<td>3.39[8]</td>
<td>93</td>
<td>--</td>
</tr>
</tbody>
</table>

CONCLUSIONS

Our goals with this work were to add to the extant body of knowledge of the 15 November 1991 solar flare by introducing new high-energy data from the CGRO. These data allowed us to confirm previous results and to compute the 2.223 MeV time constant, which is consistent (but only at the 2 $\sigma$ level) with the lowest values computed for other flares. We computed the accelerated particle spectra and subsequent energy content of these particles. We also found that the accelerated protons do not have enough energy to produce the observed white light emission.

Future Work

Once we have had the opportunity to analyze EGRET data in more depth we will further improve our understanding of the high-energy particle dynamics within this flare. If EGRET does observe extended pion emission we have further evidence that high-energy protons are reaching deep into the chromosphere or photosphere. This extended pion emission would also allow us to reclassify this event as a long duration gamma-ray flare.

The 15 November 1991 solar flare was unique because it was observed in a broad energy range with detailed X-ray images. We look forward to HESSI providing us with similarly well observed events.

ACKNOWLEDGMENTS

I would like to thank my advisor Dr. J. M. Ryan and my other committee members (Drs. M. McConnell, J. Hollweg, S. Habbal, and D. Meredith) for their help and support. I would also like to thank Drs. T. Sakao, M. Lee, T. Forbes, R. Murphy, H. Debrunner, and M. Yoshimori for our enlightening conversations. I would also like to acknowledge R. Murphy (OSSE), M. Yoshimori (YOHKOH), D. Bertsch (EGRET), and R. Schwartz (BATSE) for their help and access to data. This work was funded by the University of New Hampshire, a NASA Space Grant and NASA grants NAG5-2350, NAG5-7179, NAG5-3802, and NAS5-26645.
REFERENCES

30. Young, C.A., these proceedings.

622