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X- and Gamma-Ray Observations of the 15 November 1991 Solar Flare

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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 ~10^{23} ergs (electrons) and ~10^{27} 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^{+20}_{-15} 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

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compared to the measured count spectrum using a χ^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:

$$I(E) \propto \begin{cases} E^{-\gamma_1} \text{ for } E < E_B \\ E^{-\gamma_2} \text{ for } E > E_B \end{cases} \qquad (1)$$

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 γ_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.

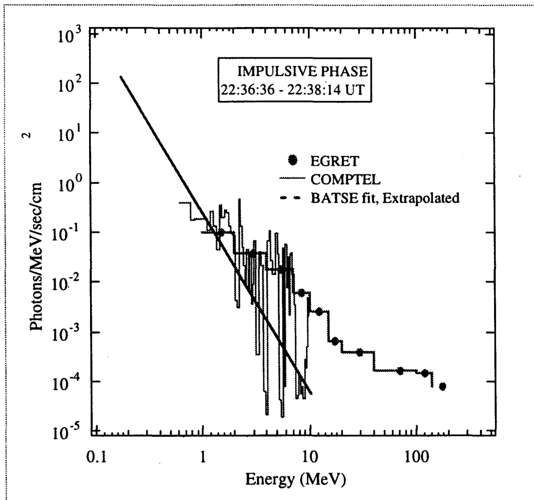

FIGURE 1. Composite Spectrum of the impulsive phase of the 15 November 1991 solar flare.

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 αT and the power law, parameterized by s. Our values (bold) and previously published values of αT 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} 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} ergs[6].

TABLE 1. Shape of accelerated proton spectra.

Fluence Line Ratio	Value	αT	s
$\phi_{4.4}/\phi_{0.42}$	0.035 – 0.065[13]	--	--
$\phi_{4.4}/\phi_{2.223}$	**0.52 ± 0.14**	0.009±0.002[11-12]	**4.5-5**
$\phi_{4-7}/\phi_{2.223}$	**1.6 ± 0.34**	**0.008 -0.015**	**4-5**
$\phi_{4-7}/\phi_{2.223}$	--	0.010 ± 0.002[25]	**4-5**
$\phi_{4.4}/\phi_{6.13}$	**2.11 ± 0.47**	--	--
$\phi_{1.63}/\phi_{6.13}$	**4.95 ± 1.0**	--	**4.5-5.5**

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 τ using the expression

$$F_{2.223MeV}(t) \propto \int_{-\infty}^{t} S(t')e^{-(t-t')/\tau}dt'. \qquad (2)$$

This time constant τ is a function of the neutron decay time as well as proton and ^{3}He neutron capture times. Subsequently, τ can provide information about proton and ^{3}He densities. We found the best fit to be 26^{+20}_{-15} s, which is consistent at the 2σ level with values of ~70 s found for other flares.

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

Given our τ and a typical chromospheric density, we find a ^{3}He/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 τ.

Accelerated Electrons

Table 2 is a summary of spectral indices from various instruments. Included are satellite viewing angles, power law spectral indices below (γ_1) and above (γ_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} ergs.

TABLE 2. Spectral Indices of Accelerated Electrons During Impulsive Phase.

Satellite (Viewing Angle)	γ_1	E_B (KeV)	γ_2
BATSE (~20°)	2.66 ± 0.27	168 ± 51	3.61 ± 0.23
OSSE (~20°)	3.0 ± 0.7	100	--
Yohkoh (~20°)	2 – 4.5[19] 3.7 ± 0.3[31]	93	--
PVO (~52°)	--	150	3.37 ± 0.05[15]
Ulysses (~80°)	3.08[8]	166(γ_1), 150 (γ_2)	2.72 ± 0.07[15]
Yohkoh (HXS)	3.20[8]	87	3.82[2] 3.70 ± 0.03[15]
Yohkoh (HXT)	3.39[8]	93	--

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 σ 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.

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REFERENCES

1. Aschwanden, M.J., Kosugi, T., Hudson, H.S., Wills, M.J., and Schwartz, R.A., *Astrophys.J*, **470**, 1198, (1996).
2. Aschwanden, M.J., Wills, M.J., Hudson, H.S., Kosugi, T., and Schwartz, R.A., *Astrophys.J*, **468**,398,(1996).
3. Canfield, R.C., Hudson, H., Leka, K.D., Mickey, D.L., Metcalf, T.R., Wuelser, J.-P., Acton, L.W., Strong, K.K.T., Kosugi, T., Sakao, T., Tsuneta, S., Culhane, J.L., Phillips, A., and Fludra, A., *Publ. Astron. Soc. Japan.*, **44**, No.5, L111, (1992).
4. Canfield, R.C. and Reardon, K.P., *Sol. Phys.*, **182**, 145, (1998).
5. Culhane, J.L., et al., *Adv. Space Res.*, **13**, No. 9, 303, (1993).
6. Hudson, H.S., Acton, L.W., Hirayama, T., and Uchida, Y., *Publ. Astron. Soc. Japan*, **44**, No. 5, L77, (1992).
7. Inda-Koide, M., Makishima, K., Kosugi, T., and Kaneda, H., *Publ. Astron. Soc. Japan*, **47**, 661, (1995).
8. Kane, S.R., Hurley, K., McTiernan, J.M., Boer, M., Niel, M., Kosugi, T., and Yoshimori, M., *Astrophys.J*, **500**,1003, (1998).
9. Kane, S.R., Hurley, K., McTiernan, and J.M, Sommer, M., *Adv. Space Res.* **13**, No. 9, 241, (1993).
10. Kane, S.R., McTiernan, J.M., Loran, J., Lemen, J., Yoshimori, M., Ohki, K., and Kosugi, T., *Adv. Space Res.*, **13**, No. 9, 237, (1993).
11. Kawabata, K., Yohimori, M., Suga, K., Morimoto, K., Hiraoka, T., Sato, J., and Ohki, K., *Astrophys.J Suppl. Ser.*, **90**, 701, (1994).
12. Kawabata, K., Yohimori, M., Suga, K., Morimoto, K., Hiraoka, T., Sato, J., and Ohki, K., in *Proceedings of Kofu Symposium*, NRO Report No. 360, 123, (1994).
13. Kotov, YU.D., Bogovalov, S.V., Endalova, O.V., and Yoshimori, M., *Astrophys.J*, **473**, 514, (1996).
14. Matthews, S.A., Brown, J.C., and van Driel-Gesztelyi, L., *Astron. Astrophys.*, **340**, 277, (1998).
15. McTiernan, J.M., Kane, S.R., Hurley, K., Laros, J.G., Fenimore, E.E., Klebsadel, R.W., Sommer, M., and Yoshimori, M., in *Proceedings of Kofu Symposium*, NRO Report No. 360, 389, (1994).
16. Sakao, T., Ph.D. Thesis, National Astronomical Observatory, Japan, (1994).
17. Sakao, T., Kosugi, T., and Masuda, S., in *Proceedings of Observational Plasma Astrophysics, Five Years of Yohkoh and Beyond*, Kluwer Academic Publishers, (1998).
18. Sakao, T., et al., *Publ. Astron. Soc. Japan*, **44**, No. 5, L83, (1992).
19. Sakao, T., Kosugi, T., Masuda, S., Yaji, K., Inda-Koide, M., and Makishima, K., in *Proceedings of Kofu Symposium*, NRO Report No. 360, 169, (1994).
20. Sylwester, B. and Sylwester J., Evolution of Yohkoh Observed White Light Flares, Kluwer Academic Publishers, 2000 (in press).
21. Takakura, T., Kosugi, T., Sakao, T., Makishima, K., Inda-Koide, M., and Masuda, S., *Publ. Astron. Soc. Japan*, **47**, 355, (1995).
22. Wülser, J.-P., Canfield, R.C., Acton, L.W., Culhane, J.L., Phillips, A., Fludra, A.J., Sakao, T., Masuda, S., Kosugi, T., and Tsuneta, S., *Astrophys.J*, **424**, No.1, 459, (1994).
23. Yoshimori, M., Kawabata, K., and Ohki, K., in *Proceedings of the XXIII International Cosmic Ray Conference*, University of Calgary, (1993).
24. Yoshimori, M., Morimoto, K., Suga, K., and Matsuda, T., in *Magnetodynamic Phenomena in the Solar Atmosphere – Prototypes of Stellar Magnetic Activity*, Kluwer Academic Publishers, (1996).
25. Yoshimori, M., Suga, K., Morimoto, K., Hiroko, T., Sato, J., Kawabata, K., and Ohki, K., *Astrophys.J Suppl. Ser.*, **90**, 639, (1994).
26. Yoshimori, M., Takai, Y., Morimoto, K., Suga, K., and Ohki, K., *Publ. Astron. Soc. Japan*, **44**, No. 5, L107, (1992).
27. Ramaty, R., Mandzhavidze, N., and Kozlovsky, B., in *Proceedings of High Energy Sol. Phys.*, Greenbelt Maryland, AIP # 374, (1995).
28. Ramaty, R., Mandzhavidze, N., Kozlovsky, B., and Murphy, R.J., *Astrophys.J Lett.*, **455**, L193, (1995).
29. Ramaty, R., Mandzhavidze, N., Kozlovsky, B., and Skibo, J.G., *Adv. Space. Res*, **13**, 275, (1993).
30. Young, C.A., these proceedings.
31. Yoshimori, M. personal communication, (2000).