OBSERVATIONS OF INTERPLANETARY ENERGETIC CHARGED PARTICLES FROM GAMMA-RAY LINE SOLAR FLARES

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ABSTRACT

Observations of interplanetary energetic ions (H^+; $5 \leq E_H \leq 20$ MeV, He, C, O, Fe; $1 \lesssim E_i \lesssim 20$ MeV/nucleon) and electrons ($115 \leq E_e \leq 1300$ keV) from the 7 June, 21 June and 1 July 1980 γ-ray line solar flares are presented. The observations are from the Max-Planck-Institut/University of Maryland Ultra Low Energy Wide Angle Telescope aboard the ISEE-3 spacecraft. Both June flares produced relatively low intensity proton events at earth with peak intensities at 10-20 MeV $\sim 5 \times 10^{-2}$ protons $(cm^2 \text{ sec sr MeV})^{-1}$. Neither flare showed evidence of being enriched in either ^{3}He or Fe at $\sim$1 MeV/nucleon. The 1 July flare produced no observable ion or electron enhancements.

1. Introduction

Gamma-ray line emission from the sun was first observed in the great flares of 4 August and 7 August 1972 by Chupp et al.[1] Solar flares which produce γ-ray line emission provide a unique opportunity to study ion acceleration phenomena in flares. For only in such flares can information on the accelerated ion population within the solar atmosphere be obtained by direct observations.[2] This information combined with interplanetary energetic charged particle data can provide the most stringent constraints on ion acceleration phenomena.

The purpose of this brief paper is to present the initial results from the Max-Planck-Institut (MPI)/University of Maryland (UM) experiments on ISEE-3 on interplanetary energetic charged particles from the 7 June, 21 June and 1 July γ-ray line solar flares (GRLF).

2. Instrument Description

The energetic particle data discussed in this paper are from the MPI/UM Ultra Low Energy Wide Angle Telescope (ULEWAT), aboard the ISEE-3 spacecraft. The ULEWAT is a double dE/dx versus E, thin-window, flow-through proportional counter/solid state detector composition telescope. For a detailed description of ULEWAT see Hovestadt et al.[3]

3. Gamma-Ray Line Flare Identification

From the launch of the Solar Maximum Mission (SMM) spacecraft, 14 February 1980, through the period for which we have reduced our ULEWAT data, 20 July 1980, the SMM Gamma Ray Experiment (GRE) detected γ-ray

lines from three flares. The photon characteristics of these GRLF are summarized in Table 1.

Table 1. Gamma-Ray Line Flare Characteristics

Flare Date (1980)	Hα onset	X-ray Max	Location	Active Region	Classification Hα	Classification X-ray	Radio Bursts(1) II	III	IV	$^2H^* \rightarrow {}^2H + 2.2$ MeV Intensity(2)(3) Peak/Aug. 72	Integral/Aug. 72
7 June	0309	0312	N14W70	2495	SB	M7	Y	Y	Y	~1	$\sim 10^{-1}$
21 June	0048	0119	N17W91	2502	1B	X2	Y	Y	Y	?(4)	
1 July(5)	1618	1628	S12W38	2544	1B	X2	Y	Y	N	~1/2	$\sim 5\times10^{-2}$

(1) Y refers to observed, N not observed.
(2) Values given are for the ratio of peak [integral] intensity of the $^2H^* \rightarrow {}^2H + \gamma(2.2\ MeV)$ line to that observed in the 4 August 1972 GRLF.
(3) From Ryan et al.[4]
(4) The peak of the 2.2 MeV line was obscured by continuum γ-rays. When the line emerged from continuum the intensity ~the 1 July 1980 GRLF.
(5) This GRLF was also a white light flare.[5]

We have identified the interplanetary energetic particle event depicted in Figure 1 as originating from the 7 June 1980 GRLF. This identification is based on: (1) a time delay of 21 ± 1 minutes between the hard x-ray maximum at the sun and the arrival time of 0.44-1.3 MeV electrons at ISEE-3, (2) the W70° heliographic longitude of the GRLF, and (3) the absence of any other large hard x-ray flares within two hours of the observed particle event. No solar wind data at earth are available for this period.

Figure 1 presents 3 hour averages of several ULEWAT counting rates. The solid circles represent $Z > 2$ ions with $12 \lesssim E_i \lesssim 40$ MeV/nuc. The triangle represents He with $5 \leq E_\alpha \leq 20$ MeV. The short horizontal line in the lower right hand corner gives the upper-limit for He 5-20 MeV/nuc and $Z > 2$ ~12-40 MeV/nuc particles.

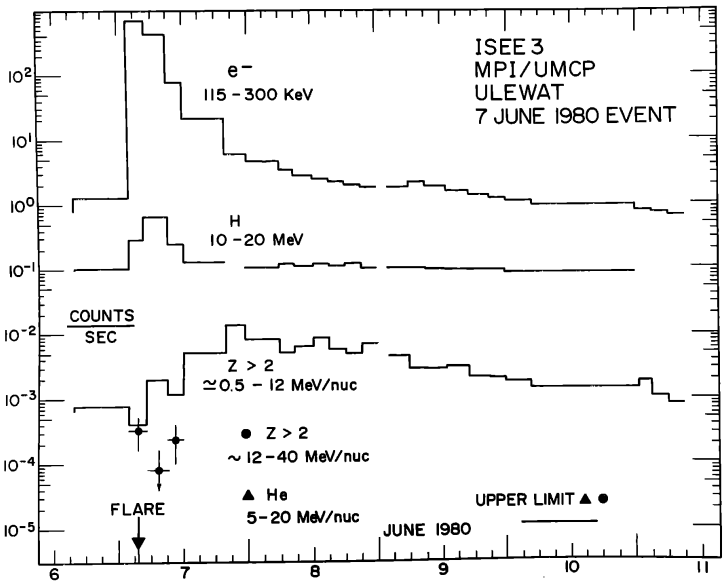

Figure 1

We have tentatively identified the first of two interplanetary energetic particle enhancements depicted in Figure 2 as originating from the 21 June 1980 GRLF. The onset of the second enhancement is indicated by the factor of two increase in 115-300 KeV electrons and 10-20 MeV protons intensity at ~0 UT on 23 June. The onset for the $Z > 2$ (~0.5-12 MeV/nuc) ions in this enhancement is not as clear and probably occurs ~3-6 UT on 23 June. The identification of the first event in Figure 2 with the 21 June 1980 GRLF is based on: (1) a time delay of 34 ± 1 minutes between the hard x-ray minimum at the sun and the arrival of 0.44-1.3 MeV electrons at ISEE-3, and (2)

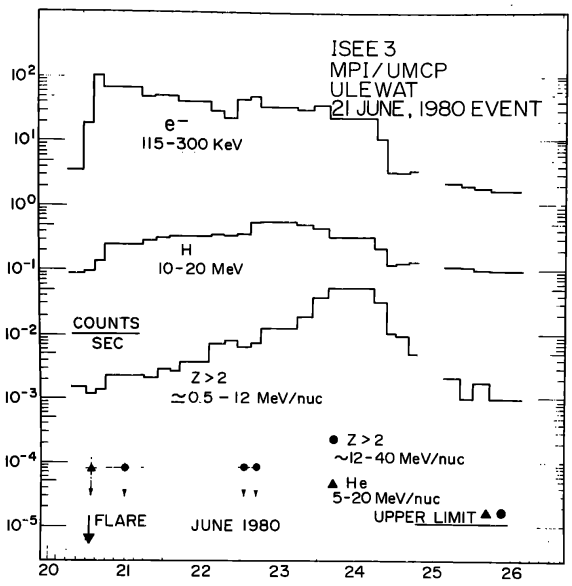

Figure 2

the W91° heliographic longitude of the GRLF. No solar wind data, at earth, are available for this period.

We are unable to find any interplanetary energetic particle event that is associated with the 1 July GRLF, in either the ULEWAT data or data from the UM/MPI instrustrument aboard the earth-orbiting IMP-8 spacecraft. No solar wind data, at earth, is available for 1 July 1980. However, there are solar wind data from IMP-8 for 30 June 1980. The observed solar wind velocity, on this day was $\tilde{-}$ 300 kms^{-1}.[6] This corresponds to an earth-sun flux tube connection at ~W77° while the GRLF occurred at W38°, a difference of 40° in connection longitude.

4. Interplanetary Fluxes and Energy Spectra

An analysis of the GRE γ-ray data from the 3 GRLF indicates that protons were accelerated up to at least 10-20 MeV[4]. While it is not possible here to make a detailed analyses of the flux, energy spectra and anisotropy time histories of the 7 June and 21 June particle events in order to estimate the injected particle population at the sun, we will present particle fluxes and spectral indices γ at the time of maximum particle intensities. This information is given in Table 2. The values here are derived from 3 hour average counting rates. The γ's are calculated from a least squares fit to the equation $J = A\varepsilon^{-\gamma}$ where ε = Energy/nucleon, and J is the differtial intensity. For the 1 July 1980 GRLF only upper limits of the particle flux can be given.

Table 2. Peak Particle Flux and Spectra Indices

Flare Date	Protons $(cm^2\ sec\ str\ MeV)^{-1}$		Electrons $(cm^2\ sec\ str)^{-1}$			Proton γ	Electron γ
	5-10 MeV	10-20 MeV	115-300 keV	300-440 KeV	0.44-1.3 MeV		
7 June	1.5×10^{-1}	6.8×10^{-2}	4.5×10^{3}	3.1×10^{2}	3.7×10^{1}	2.1	3.5
21 June	3.1×10^{-2}	1.8×10^{-2}	6.7×10^{2}	1.5×10^{2}	2.2×10^{1}	1.8	2.5
1 July	$<1.6\times10^{-2}$	$<1.2\times10^{-2}$	<2.5	$<7.6\times10^{0}$	$<1.9\times10^{0}$	-	-

5. Elemental and Isotopic Composition

Because of the low Z > 1 ion flux in both 7 June and 21 June 1980 GRLF associated particle event we are able to determine composition ratios at equal energy per nucleon Γ, in only one ULEWAT energy range. The relative composition ratios are presented in Table 3.

Table 3. Abundances for γ-ray Line Flares

Flare	r(C/O)	r(Fe/O)	r(^{3}He/^{4}He)
7 June 1980	0.50±0.08(6)	0.027±0.027(6)	<10^{-2}(7)
21 June 1980	0.79±0.32(6)	<0.07(6)	<10^{-1}(7)
August 1972 (1)(2)(3)	0.47±0.04	0.07±0.03(5)	10^{-3}
^{3}He rich(4)	0.23	1.3	>2x10^{-2}
"Normal"(4)	0.54	0.15	<10^{-3}
Photosphere(4)	0.6	0.05	<10^{-4}
Corona(4)	1.0	0.093	∿10^{-3}

(1) Date from Pioneer 10 at 2.2 AU for 3-15 August.
(2) Date for 7.5-46.5 MeV/nuc.
(3) Date from Webber et al.
(4) From Gloeckler[8] for 1-20 MeV/nuc.
(5) For Z ≥ 16 ions
(6) For 1-1.8 MeV/nuc.
(7) For 0.7-0.9 MeV/nuc.

For the 7 June event the data are summed from 7 June 1200 to 8 June 2359. For the 21 June period the data are accumulated for only the first event in Figure 1 from 21 June 0000 UT to 22 June 1200 UT. For comparison we have also presented composition ratios from the August 1972 GRLFs, for ^{3}He rich flares, normal composition flares, the photosphere, and the corona.

6. Discussion and Conclusions

We conclude from results presented in Table 3 that neither the 7 June 1980, 21 June 1980 nor the August 1972 GRLF are classifiable as ^{3}He rich or as Fe rich. This is consistent with the plasma instability preheating model of the ^{3}He and Fe rich events discussed by Fisk[9]. We also note that the GRLFs in Table 3 compared to normal composition flares are depleted in Fe relative to O by a factor of 2-3.

Although the intensity of γ-ray line emission at 2.2 MeV from the 1980 GRLFs is the same order of magnitude as that from the August 1972 GRLF, the peak ∿10 MeV proton intensities in the two sets of flares differ by many orders of magnitude. Furthermore we have observed several non GRLF associated particle events with ULEWAT in which the peak proton intensity exceeds that of the GRLF associated events by 2 orders of magnitude. If the proton flux difference between events is not due to propagation effects it could indicate that there is little if any relationship between the ion population that give rise to the γ-ray line emission and the ions population that is injected into interplanetary space.

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