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ARE SOLAR GAMMA-RAY–LINE FLARES DIFFERENT FROM OTHER LARGE FLARES?

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ABSTRACT

We reevaluate evidence indicating that gamma-ray–line (GRL) flares are fundamentally different from other large flares without detectable GRL emission and find no compelling support for this proposition. For large flares observed by the *Solar Maximum Mission* (*SMM*) from 1980 to 1982, we obtain a reasonably good correlation between 4–8 MeV GRL fluences and >50 keV hard X-ray fluences and find no evidence for a distinct population of large hard X-ray flares that lack commensurate GRL emission. Our results are consistent with the acceleration of the bulk of the ~100 keV electrons and ~10 MeV protons (i.e., the populations of these species that interact in the solar atmosphere to produce hard X-ray and GRL emission) by a common process in large flares of both long and short durations.

Subject headings: Sun: flares — Sun: X-rays, gamma rays

1. INTRODUCTION

The question posed in the title has fueled controversy since the first analyses of Gamma Ray Spectrometer (GRS; Forrest et al. 1980) data from the *Solar Maximum Mission* (*SMM*). Bai (Bai et al. 1983a, b; Bai & Dennis 1985; Bai 1986), in particular, has argued that gamma-ray–line (GRL) flares are distinguished from other large flares that lack detectable GRL emission ("non-GRL" flares) by a second-step acceleration mechanism that is required to accelerate the GRL-producing protons. Bai & Dennis (1985) and Cliver et al. (1991) used a big flare syndrome (Kahler 1982) test based on >25 keV peak intensities to show that GRL flares have a significantly higher level of metric type II burst association than do comparably intense hard X-ray bursts that lack detectable GRL emission. Bai & Dennis (1985) (cf. Bai 1986) considered GRL flares occurring through 1981, and Cliver et al. (1991) extended the test through the 1982 data; in both cases the probability that the observed differences arose by chance was $\lesssim 0.5\%$. Bai & Dennis (1985) and Bai (1986) also reported that GRL flares have flatter hard X-ray spectra than non-GRL flares and exhibit characteristic delays of high-energy X-rays with respect to lower energy X-rays.

The alternative viewpoint to that of Bai (1986) is that GRL flares are not fundamentally different from other large flares and that GRL- producing protons are accelerated in all big flares. Forrest (1983) found that the >300 keV electron bremsstrahlung continuum and 4–8 MeV GRL emissions of flares were correlated down to the GRL detection threshold of the GRS. Thus Forrest (1983) and Chupp (1984) argued that all flares with continuum above 300 keV could be GRL flares, given a sensitive enough detector. Bai (1986) criticized this inference because, in his picture, MeV protons and the bulk of relativistic electrons are both accelerated by a second-step process that operates only in GRL flares. From Bai's perspective, the correlation found by Forrest (1983) was not surprising but was instead an expected result of second-step acceleration. Bai (1986) argued that there exists a population of large hard (e.g., >50 keV) X-ray flares with steep spectra (the non-GRL flares that result from a primary or "first-step" acceleration mechanism) in which a second-step process does not operate to accelerate particles to high energies. Such events should weaken any correlation in a scatter plot of >50 keV emission versus 4–8 MeV line emission for a sample of large flares.

W. T. Vestrand (1991, private communication) criticized the studies of Bai (1986) and Cliver et al. (1991) for their use of a big flare syndrome test based on peak hard X-ray intensities (counts s^{-1}). Vestrand argued that, because GRL flares are identified on the basis of their time-integrated emission or fluence (photons cm^{-2}), it would be more appropriate to look for differences in type II associations between samples of GRL flares and non-GRL flares that are matched in terms of their hard X-ray fluences. Such a parameter should also be a better indicator of total energy release or "flare size."

Following Vestrand's suggestion, and making use of data reduction/analysis programs recently completed by the Hard X-ray Burst Spectrometer (HXRBS) team that enables one to readily determine X-ray fluences, we looked for differences in type II associations of samples of GRL and non-GRL flares with comparable >50 keV fluences. In addition, we compared flare 4–8 MeV fluences with >50 keV fluences to see if the correlation reported by Forrest (1983) could be extended to lower X-ray energies.

The ratio of the flare bremsstrahlung continuum emission produced by accelerated electrons to the GRL emission produced by protons provides a measure of the electron-to-proton (e:p) ratio of interacting particles. Cane, McGuire, & von Rosenvinge (1986) were the first to show that the e:p ratios of solar energetic particle (SEP) events observed in space following flares are ordered by the flare duration, with impulsive

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flares having higher $e{:}p$ ratios. Thus we also examined the effect of flare duration on the $e{:}p$ ratio of the particles that interact at the Sun to produce X-ray and GRL emission to see if a similar relationship held.

The analysis is described in § 2, and the results are discussed in § 3.

2. ANALYSIS

2.1. *Fluence Calculation*

The HXRBS detector consists of a CsI(Na) scintillation spectrometer with a large anticoincidence shield (Orwig, Frost, & Dennis 1980). The HXRBS Event Catalog (Dennis et al. 1991) contains 7045 events for the three years 1980–1982. As the first step in our procedure for obtaining fluences, we required that an event have a detectable flux in Channel 3 as reported in the HXRBS Catalog. From 1980 February to 1982 December, the low-energy cutoff for this channel increased from 49 to 63 keV. Of the events with a signal in Channel 3, we selected those having durations >200 s and/or peak count rates, integrated over all channels, of >100 counts s^{-1}. Nonsolar events and events flagged as having "noisy data" were not considered.

Each selected HXRBS event was then broken down into discrete time intervals, consisting of integral multiples of the HXRBS 128 ms accumulation time, by the following procedure. The burst was initially divided into a series of contiguous intervals with each interval containing the minimum number of 128 ms accumulation times needed to give ≥ 400 counts. These intervals were typically less than 10 s in duration since the preflare background rate was approximately 40 counts s^{-1}. Contiguous intervals with ≥ 400 counts were then joined together until the rate in the next interval differed from the mean rate in the intervals already joined by $>2.6\ \sigma$. The value of σ was calculated assuming Poisson counting statistics, i.e., $\sigma =$ square root (number of counts recorded in that interval) divided by the accumulated live time. Thus the actual intervals used for the analysis all contain ≥ 400 counts and significant fluctuations in the count rate are preserved at the $2.6\ \sigma$ level.

The integral count rate above preevent background for each interval was deconvolved to approximate the incident photon flux, which was assumed to have a power-law spectrum of the form $E^{-\gamma}$, using conversion factors generated by modeling the detector response to an incident flux with such a spectrum. A least-squares spectral fit for each interval was performed using an automated procedure, and the fit parameters were stored in a "summary file." There were 2878 such events during 1980–1982. Only flare intervals with power-law slopes greater than 1.1 or less than 7.0 were used in the fluence calculations. For $\gamma < 1.1$, the integral of the X-ray spectrum diverges, while values of $\gamma > 7.0$ may reflect a thermal spectrum and are, in any case, unreliable because of the relatively poor energy resolution of the CsI(Na) detector. To ensure that we considered only detected >50 keV emission and were not merely integrating background noise from erroneous spectral fits both early and late in flares when the counting rate is low, we followed the procedure of Crosby, Aschwanden, & Dennis (1993) and considered only those intervals for which the calculated value of the thick-target energy in >50 keV electrons exceeded the value of this parameter averaged over all intervals that met the above criteria. The >50 keV fluence value for a given event was then obtained by summing the contributions from all valid intervals.

As a check on the accuracy of the HXRBS fluences obtained by the above method, we compared our >50 keV fluences with preliminary 40–140 keV fluences measured by the GRS on *SMM* (W. T. Vestrand 1992, private communication) for a sample of large flares observed from 1980 to 1982. The result of the HXRBS-GRS comparison is shown in Figure 1. The plot contains nearly all HXRBS events with >50 keV fluences ≥ 5000 photons cm^{-2} for which the peak of the burst was observed, and a decreasing fraction of such well-observed events for smaller fluences.

The circled data points in Figure 1 indicate events affected by pulse pile-up (Kane & Hudson 1970). The presence of pulse pile-up in an event is revealed by a comparison of the outputs from the two X-ray detectors on GRS. One of these detectors has an additional iron filter to block lower energy photons and, therefore, is less susceptible to pulse pile-up distortion of counting rates. Any difference in the output of the two detectors for a common energy range can be attributed to a greater degree of pulse pile-up in the detector without this filter. In terms of their level of "shielding," the two GRS X-ray detectors bracket the HXRBS X-ray detector, one being more heavily shielded and one less so. Thus an indication of pile-up in the GRS X-ray detectors indicates that the output from the HXRBS detector may also be affected, especially because the HXRBS detector is larger than the GRS detectors. The fact that the circled data points in Figure 1 generally lie above the least-squares fit line is consistent with the relative susceptibility of the HXRBS and GRS detectors to pulse pile-up. The discrepancy between GRS and HXRBS fluences for one of the two data points flagged with a question mark is partly due to different times analyzed for the two instruments. But the causes of the remaining discrepancy for this event and of the entire difference for the other such flagged event are unknown.

As shown in Figure 1, there is good agreement between the two fluence measures, especially when the circled data points are ignored. The dashed line in Figure 1 is the least-squares fit to the "good" data points (not circled or flagged with a "?"); it can be used to correct HXRBS fluences for pulse pile-up affected events for which the GRS 40–140 keV fluence (from

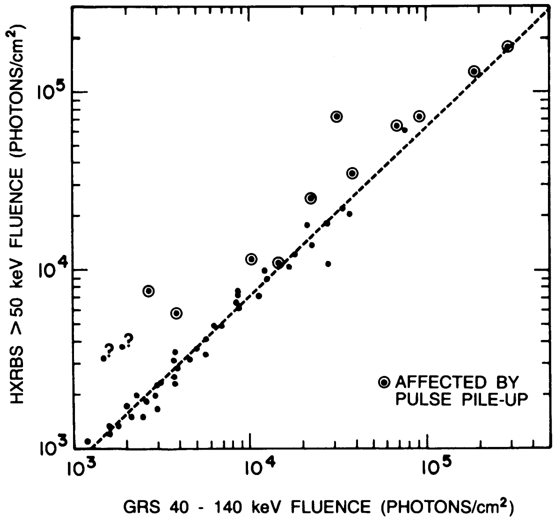

FIG. 1.—Plot of HXRBS >50 keV fluence vs. GRS 40–140 keV fluence. Circled data points indicate events affected by pulse pile-up. For the two events flagged with "?," the cause of the discrepancy between the GRS and HXRBS X-ray fluences is unknown.

the more heavily shielded detector) has been determined. The assumption underlying any such correction is that the GRS X-ray detector with the additional filter is not affected by pulse pile-up. This assumption may not be valid for intense events, particularly those with a soft spectrum, and for such events the corrected >50 keV fluence will only be an upper limit.

2.2. *Reevaluation of Previous Studies*

The left-hand side of Figure 2 contains histograms of the peak HXRBS >25 keV count rate for the GRL flares (*top*) and non-GRL flares (*bottom*) used in Bai's (1986) big flare syndrome test. The GRL flares and control group are reasonably well matched in terms of this parameter; the median peak HXRBS rate for the GRL flares (2.80×10^4 counts s^{-1}) is a factor of 1.5 larger than the median peak rate (1.90×10^4 counts s^{-1}) for the control events. However, when the >50 keV fluences (corrected for pulse pile-up using the dashed line in Fig. 1) for these two groups are compared (right-hand side of Fig. 2), we see that the distributions are not well matched. The median fluence of the GRL sample is 1.0×10^4 photons cm^{-2}, a factor of 6.7 larger than the 1.5×10^3 photons cm^{-2} median of the control group. Similar differences in peak count rates and fluences exist between the GRL and control events considered by Cliver et al. (1991) (Fig. 3). The median peak intensity of their GRL flares (2.26×10^4 counts s^{-1}) is a factor of 2.2 larger than the median peak rate of the non-GRL flares (1.05×10^4 counts s^{-1}). In comparison, the median fluence of the GRL flares (9.05×10^3 photons cm^{-2}) is a factor of 8.2 larger than the median fluence of the control group (1.11×10^3 photons cm^{-2}). Thus it appears that the big flare syndrome tests used by Bai & Dennis (1985) and Cliver et al. (1991) were not valid because the events in their control groups of non-GRL flares were intrinsically smaller than the GRL flares. The higher associations they obtained between GRL flares and type II bursts are consistent with the big flare syndrome and do not give insights into the proton acceleration process.

GRL flares, as detected by *SMM*, are clearly "big" flares. For the 1980–1982 period considered by Cliver et al. (1991), 19 of the 20 largest >50 keV fluence events had detectable GRL emission (right-hand side of Fig. 3; all 20 had associated type II and/or type IV radio bursts). The 20 largest >50 keV fluence events span more than an order of magnitude in this parameter. The only non-GRL event of the 20 was an event on 1982 July 12 with a >50 keV fluence, severely distorted by pulse pile-up, of 32,380 photons cm^{-2}. No pile-up correction was made for this event; the distortion was so severe that any value obtained for the 40–140 keV fluence from the GRS X-ray detector would have been meaningless (W. T. Vestrand 1993, private communication).

We used a big flare syndrome test similar to that of Bai (1986) and Cliver et al. (1991), but based on the >50 keV fluence rather than the peak >25 keV count rate, to determine the significance of the association of metric type II bursts with GRL flares (Table 1). The test covers all HXRBS events (for which the peak count rate was observed as determined from an examination of the time profile and/or comparison with microwave data) with >50 keV fluences in the range 10^3–10^4 photons cm^{-2} that were observed from 1980 to 1982. For events with larger fluences, there is only one control event; for events with smaller fluences, there is only one GRL event. Type II data, routinely reported by Culgoora, Weissenau, and

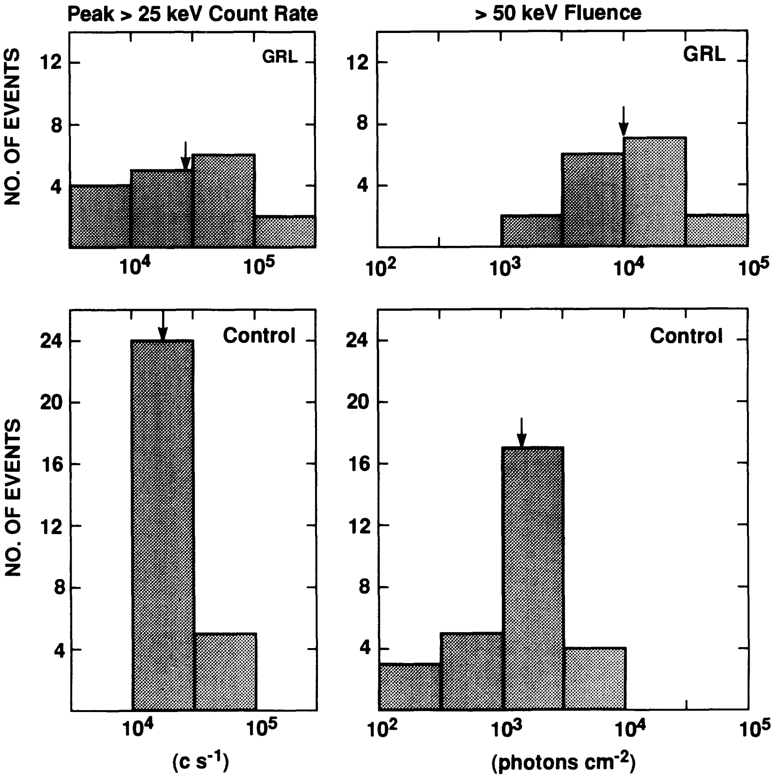

FIG. 2.—*Left-hand side*: Comparison of peak >25 keV HXRBS count rates of GRL and control events considered by Bai (1986). Arrows indicate the median values of the distributions. *Right-hand side*: Comparison of >50 keV fluences for the same two groups of events.

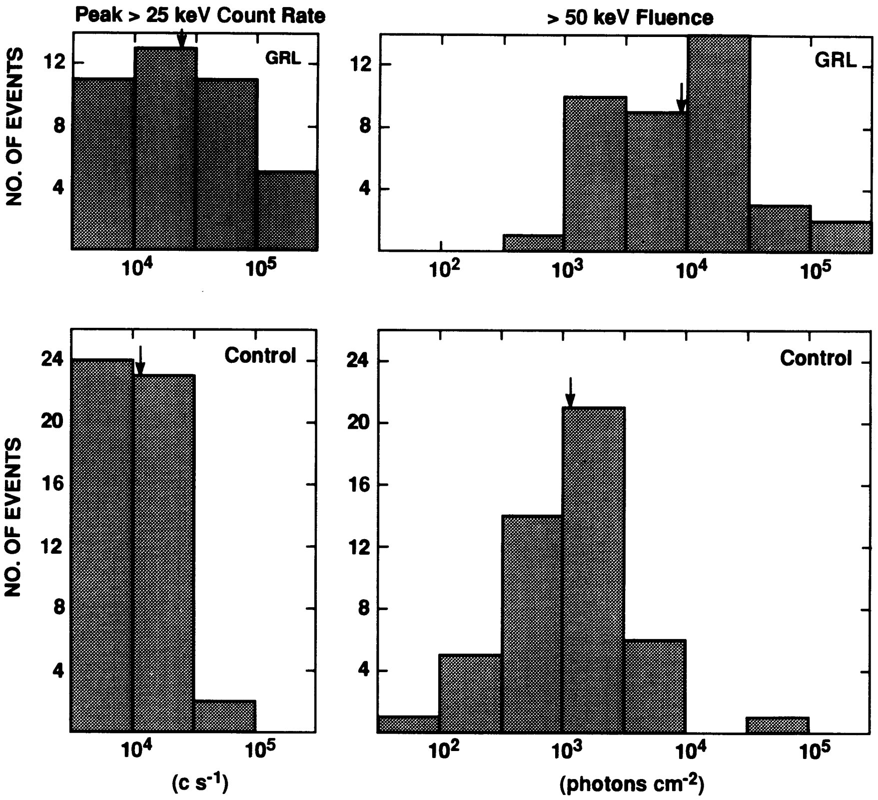

FIG. 3.—*Left-hand side*: Comparison of peak >25 keV HXRBS count rates of GRL and control events considered by Cliver et al. (1991). Arrows indicate median values of the distributions. *Right-hand side*: Comparison of > 50 keV fluences for the same two groups of events.

Harvard (Fort Davis) during this period, were taken from Solar-Geophysical Data. Only HXRBS events for which one or more of these stations was observing were considered. Within this 10^3–10^4 photon cm^{-2} range of fluences, the sample of GRL flares have a somewhat larger (~50%) median fluence than that of the non-GRL flares. Yates's χ^2 test (Langley 1970) shows that the probability that the difference in type II association between the two groups of events in Table 1 (with and without GRL emission) is due to chance is ~10%, a marginally significant result. If we consider metric type IV bursts reported by any of these stations to be an acceptable proxy for type II emission (cf. Bai 1986, Cliver et al. 1991), the resultant probability that the differences in type II (and/or type IV) association are due to random chance increases to ~35% (Table 1, numbers in parentheses in right-hand column). Thus the results obtained when the samples of GRL and control events are more evenly matched in terms of their >50 keV fluences are considerably weaker than those obtained from the tests used by Bai & Dennis (1985) and Cliver et al. (1991) and no longer constitute compelling evidence of a difference between GRL and non-GRL flares.

TABLE 1

ASSOCIATION OF INTERMEDIATE FLUENCE (10^3–10^4 photons cm^{-2}) HXRBS FLARES WITH TYPE II BURSTS (OR TYPE II AND/OR TYPE IV BURSTS) AND GRL EMISSION, 1980–1982

TYPE II ASSOCIATION? (OR TYPE II AND/OR TYPE IV ASSOCIATION?)	4–8 MEV EXCESS (>2 σ)?	
	Yes	No[a]
Yes	12	19 (24)
No	7	31 (26)

[a] The number of events with type II association includes cases of events with type II *and* type IV emission; events with only type IV emission are added to this figure to give the number in parentheses (and subtracted from the corresponding figure in the bottom row to give the number in parentheses there).

2.3. 4–8 MeV *Fluence versus* >50 keV *Fluence*

Figure 4 is a plot of 4–8 MeV fluence versus >50 keV fluence (corrected for pulse pile-up as necessary and when possible) for all HXRBS summary file events occurring from 1980 to 1982 with >50 keV fluences ≥500 photons cm^{-2}. The 4–8 MeV fluences were taken from Cliver et al. (1989). The data points shown as crosses in this figure are for non-GRL flares; the values of the ordinates for these points correspond to a 4–8 MeV fluence upper limit of ~0.5 photons cm^{-2} (plotted between 0.35 and 0.9 photons cm^{-2} because of space limitations), the nominal detection threshold of the GRS for GRL emission. The data points with horizontal lines drawn through them indicate that a correction for pulse pile-up (using Fig. 1) has been applied to the >50 keV fluence. A relationship similar to that depicted in Figure 4 has been found to exist between the GRS 40–140 keV fluence and the 2.2 MeV neutron capture line fluence (Vestrand 1991). Figure 5 shows an updated version (from Vestrand 1988) of the correlation obtained by Forrest (1983) between the >300 keV fluence and the 4–8 MeV fluence for all flares with >300 keV emission observed by GRS during the period 1980–1985. The plots in Figures 4 and 5 are similar in appearance. In both cases the scatter increases for lower energies, although to a greater degree in Figure 4. There is no "population" of large >50 keV

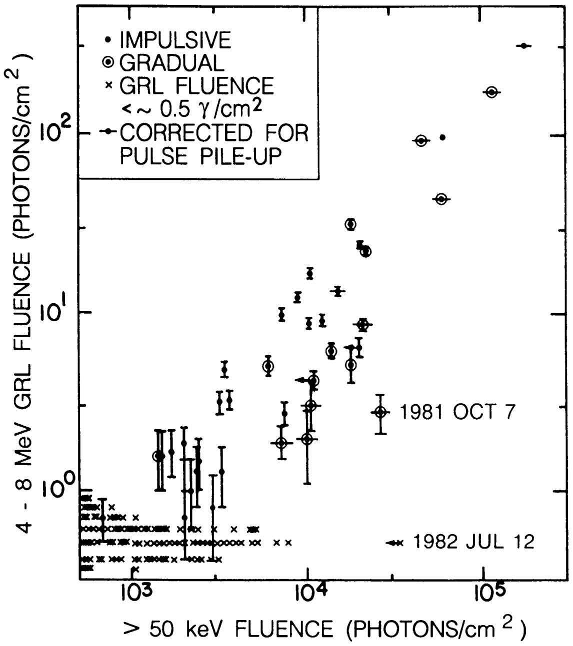

FIG. 4.—Plot of GRS 4–8 MeV GRL fluence vs. HXRBS >50 keV fluence, 1980–1982. See inset for explanation of various types of data points. A leftward-pointing arrow on a data point indicates an event affected by pulse pile-up for which no correction was made.

fluence events that lack detectable GRL emission in Figure 4. There are two outliers, labeled with their dates, that fall below the general trend of the data. One of these is the event on 1982 July 12 that lacked detectable GRL emission; the other outlier occurred on 1981 October 7. The plotted >50 keV fluence for the 1981 October 7 event has been corrected for pulse pile-up; as mentioned in § 2.2, this was not possible for the 1982 July 12 event. Leftward-pointing arrows on three data points, including that of 1982 July 12, indicate events which show evidence for pulse pile-up but for which corrections were not made because the 40–140 keV fluence was not determined. As noted in § 2.2, however, all of the data points corrected for pulse pile-up represent, in a sense, upper limits because the 40–140 keV fluence obtained from the more heavily shielded X-ray detector on GRS that is used to obtain a corrected >50 keV fluence via Figure 1 may also be distorted by pulse pile-up.

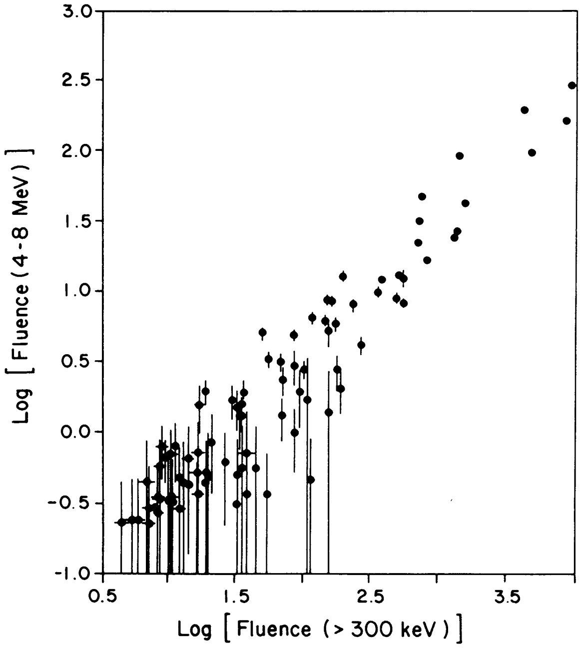

FIG. 5.—Plot of 4–8 MeV excess vs. >300 keV electron bremsstrahlung continuum fluence for flares observed by the GRS from 1980 to 1985 (from Vestrand 1988).

The circled data points in Figure 4 represent long-duration flares following the classification scheme of Cliver et al. (1989) (cf. Cane et al. 1986, Bai 1986). As can be seen in the figure, there is a tendency for these events to have higher $e:p$ (i.e., >50 keV bremsstrahlung fluence: 4–8 MeV GRL fluence) ratios than do the impulsive flares; their data points tend to lie to the right of the trend line. (The large [>3000 photons cm^{-2}] non-GRL flares, having data points shown as crosses, are also characteristically gradual events.) The difference in $e:p$ ratios between the gradual and impulsive flares is not great, about a factor of 2 in the medians, and may be due to the relative sensitivities of the HXRBS and GRS detectors late in long-duration events when GRL fluxes fall below the detection threshold. For comparison, Kallenrode, Cliver, & Wibberenz (1992) found a difference of a factor of $\lesssim 10$ between the average $e:p$ ratios of SEPs from gradual and impulsive flares. For SEP events, however, the difference is in the opposite direction with higher $e:p$ ratios observed in SEP events associated with impulsive flares. The small, possibly instrumental, difference that we find between $e:p$ ratios of interacting particles from gradual and impulsive flares is consistent, to first order, with the recent result of Ramaty et al. (1992) that the ratio of the numbers of interacting 0.5 MeV electrons to 10 MeV protons is independent of flare duration.

There is evidence for a class of impulsive γ-ray flares, called electron-dominated events (Rieger & Marschhäuser 1990), in which line emission is missing or muted. While such events might be representatives of the population of large "first-step" non-GRL flares argued for by Bai (1986) in the two-step scenario, any such identification is problematical because the bremsstrahlung continuum in electron-dominated events extends beyond 10 MeV (up to 60 MeV in certain cases) and the spectra exhibit a tendency to flatten with increasing energy. There were eight such flares in the total sample, 1980–1989, of GRS flares which were intense enough to be spectrally analyzed (Rieger & Marschhäuser 1990). Three of these flares were observed during the 1980–1982 period we considered (E. Rieger 1990, private communication), 1980 June 4, 1980 June 29, and 1982 June 15. Each of these flares had >50 keV fluence in the range from 2 to 4 × 10^3 photons cm^{-2}; thus, their data points lie in the lower left-hand side of Figure 4 where the scatter is greatest. Because of the subtraction technique used to determine the nuclear excess (Vestrand 1988), the line emission in these events is overestimated (Bech, Steinacker, & Schlickeiser 1990). However, even if we reduce the GRL emission observed in these events from the deduced values of $\sim$2–5 photons cm^{-2} to the GRS instrumental background of $\sim$0.5 photons cm^{-2}, the altered data points remain within the scatter, and our basic result—the correlation of >50 keV and 4–8 MeV fluences for large flares observed from 1980 to 1982—is not changed. Nevertheless, the possibility remains that the electron-dominated events of Rieger & Marschhäuser (1990) are the largest members of a separate branch of events in Figure 4 that will become visible as the experimental threshold for γ-ray observations is reduced.

3. DISCUSSION

3.1. *Are GRL Flares Different from Other Large Flares?*

Bai (1986) identified five distinguishing properties of GRL flares: (1) delays of high-energy X-rays with respect to low-energy (50 keV) X-rays, (2) flat spectra of hard X-ray emission, (3) good association with type II/IV radio bursts, (4) HXRBS peak count rates >5000 counts s^{-1}, and (5) intense microwave emission with peak flux densities >500 sfu at 9 GHz. As Bai (1986) noted, characteristics (4) and (5) are directly attributable to the threshold of the GRS.

In regard to characteristic (3), we find a smaller difference in the level of type II radio burst association between flares with and without detectable GRL emission than has been previously reported (Bai & Dennis 1985; Bai 1986; Cliver et al. 1991). Whereas previous investigators found differences that were significant at the $<1\%$ level, we find that the probability that the observed differences arise by chance ranges from $\sim 10\%$ (type II only), a result of marginal significance, to $\sim 35\%$ (type II and/or type IV), not significant. Control groups of non-GRL flares used in earlier studies had median >50 keV fluences that were smaller by a factor of 6–8 than those of the GRL flares considered. Thus, the higher degree of type II association they found for GRL flares may be a manifestation of the big flare syndrome, i.e., the tendency for big flares to have more of everything.

Before leaving this topic, we point out that the big flare syndrome test used by us and previous authors may be fatally flawed, and that even the weak statistical differences that we find in the level of type II association of GRL and "non-GRL" flares must be viewed with caution. The big flare syndrome test we used selects flares in terms of one energetic parameter threshold (for the >50 keV fluence in our case), separates them into two groups (those with and without GRLs), and then asks if differences exist between the two groups in terms of a third energetic parameter (presence of type II emission). It stands to reason that, because of rapid energy transport in the solar atmosphere (Kahler 1982), any flare that is more energetic in one parameter is likely to be more energetic in a second; this is, in fact, a restatement of the big flare syndrome. Along these lines, it does not matter which parameter is used to obtain a sample of matched flares because as soon as a second parameter, which in itself is a reflection of flare size, is used to separate the events into two groups, the resultant groups will be inherently unequal, and their differentiation in terms of a third parameter is predictable.

Regarding characteristic (1) above, increasingly sophisticated models of particle transport and trapping (Ryan 1986; Hua, Ramaty, & Lingenfelter 1989; Miller & Ramaty 1989; cf. Cliver et al. 1986, Vestrand 1988) are capable of explaining features of spectral development such as high-energy delays that were previously attributed to particle acceleration processes.

The harder spectra of GRL flares (characteristic [2]) is an expected effect if the proton and electron spectra are coupled through a common acceleration process. Then the flares with flat hard X-ray spectra would be more likely to produce observable nuclear γ-rays. In addition, when comparing hard X-ray spectra of samples of events, it is necessary to take directivity effects into account. Vestrand et al. (1987) showed that GRS flares occurring at heliocentric angles $<60°$ from 1980 to 1986 had spectra with power-law slopes in the 25–200 keV range that were steeper by 0.51 ± 0.21 than those observed for flares located $>60°$ from disk center. For higher energies, >300 keV–1 MeV, the difference was 0.37 ± 0.11. The 14 control events with generally soft spectra considered by Bai (1986) occurred at a median heliocentric angle of 44° vs. 72° for the GRL flares.

Cliver et al. (1991) reported that GRL flares of both long and short durations were strongly (70%–90%) associated with coronal mass ejections (CMEs) and suggested that CMEs might be an additional distinguishing characteristic (necessary condition) of GRL flares. They argued that the reconnection and turbulence expected to occur in response to a CME would represent a favorable condition in the low corona for energetic particle acceleration, particularly when the CME arose from a strong field region. We still believe this to be a reasonable point of view, given growing evidence that CME onsets precede flares (e.g., Harrison et al. 1990). However, in light of the present study, the notion that the acceleration process (for particles interacting in the solar atmosphere to produce X-rays and γ-rays) in flares with CMEs is different from that in flares that lack CMEs is suspect. Since mass motions can account for a substantial fraction of the flare energy budget (Webb et al. 1980; Dulk 1980), it follows that flares associated with CMEs are likely to be more energetic than flares occurring in the absence of CMEs. Thus, the association of GRL flares with CMEs may be yet another manifestation of the big flare syndrome.

To summarize, the evidence that GRL flares are fundamentally different from other large flares without detectable GRL emission is not compelling. Several of the suggested characteristics ([2]–[5]) from Bai's (1986) list and the high degree of CME association (Cliver et al. 1991) may be big flare syndrome effects, and it is likely that the observed delays of high-energy X-rays (characteristic [1]) in GRL flares result, at least in part, from electron trapping.

3.2. *A Common Acceleration Process for* ~ 10 MeV *Ions and* ~ 100 keV *Electrons in Large Flares*

The correlation that we find in Figure 4 between >50 keV fluences and 4–8 MeV GRL fluences suggests that the bulk of ~ 100 keV electrons and ~ 10 MeV ions that interact in the solar atmosphere to produce >50 keV X-rays and 4–8 MeV GRLs, respectively, are accelerated in a common acceleration process in large flares (cf. Forrest & Chupp 1983, Kane et al. 1986) of both long and short durations. This would be the simplest explanation for the correlation. We note, in particular, the absence of a well-defined population of flares with large >50 keV fluences but without detectable GRLs. In the picture of Bai (1986), such events would be those in which the second-step process was not operating. The two high-fluence events that are deficient in GRL emission (1981 October 7 and 1982 July 12) have characteristics (delay of high-energy X-rays, at least for 1981 October 7, and type II association) that Bai & Dennis (1985) and Bai (1986) reported for "normal" GRL flares. The anomalous position of the 1982 July 12 event is presumed to result primarily from pulse pile-up in the HXRBS detector. In addition, both the 1982 July 12 and 1981 October 7 events were gradual flares, and there is a tendency in Figure 4, which may be an instrumental effect, for gradual flares to have larger $e{:}p$ ratios than impulsive events. We note that the gradual events, in general, contribute much of the scatter in the correlation plot in Figure 4. Again, while these events appear to be, as a group, slightly deficient in GRL emission, they exhibit the properties—spectral delays and type II association—that were thought to be defining characteristics of GRL flares (Bai 1986). Thus there is little evidence that gradual events, in terms of their acceleration of particles that interact in the solar atmosphere, constitute a separate "class" of flares. The common acceleration process we propose for ~ 100 keV electrons and ~ 10 MeV ions in large flares of both long and short durations could still be a second-step process, following an initial injection as envisioned by Bai (1986) (cf. Bai & Sturrock 1989, Mandzhavidze & Ramaty 1993), but such a second-step process must dominate electron acceleration down to energies $\lesssim 100$ keV rather than the >200 keV level suggested by Bai (1986).

Our conclusion regarding a single dominant acceleration mechanism in large flares refers only to those particles that interact at the Sun. The poor correlation between the numbers of interacting protons (observed via their GRL emission) and those observed in space (Cliver et al. 1989) indicates that other, or additional, acceleration processes apply for SEPs.

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