SIZE DISTRIBUTIONS OF SOLAR ENERGETIC PARTICLE EVENTS

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Abstract. We obtained size distributions of peak fluxes of solar energetic proton (24-43 MeV) and electron (3.6-18.5 MeV) events observed with the NASA/Goddard particle detectors on IMP-8. The peak differential fluxes of the 92 proton events in our sample have a power law size distribution with a slope of -1.13 ± 0.04. For 67 electron events the slope was -1.30 ± 0.07, although it may be as steep as -1.42 ± 0.04 if the count in the lowest flux bin is "rolled over". The flatter size distribution obtained for energetic proton events, relative to both the peak flux distribution of the electrons and fluence distributions of flare electromagnetic radiations, is consistent with the result obtained by van Hollebeke, Ma Sung, and McDonald (1975), and does not support the concept that all flares are proton flares. We separated both the proton and electron events into two classes, "gradual" and "impulsive", based on the duration of their parent soft X-ray flares and constructed size distributions for these subgroups. For both particle species, there is a suggestion that the "impulsive" events have a steeper power law distribution than the "gradual" events, but the sample sizes are small and differences in slopes are within the statistical uncertainties.

1. Introduction. Hudson (1978) pointed out that the power law size distribution of solar energetic protons (SEPs) was significantly flatter than distributions obtained for flare electromagnetic emissions. While the X-ray and radio peak fluxes examined by various authors had distributions with a power law slope of ~ -1.8, van Hollebeke, Ma Sung, and McDonald (1975) obtained a slope of -1.15 ± 0.05 for the peak fluxes of 20-80 MeV protons observed by IMP-4 and IMP-5 from May 1967 - December 1972. This difference prompted Hudson to suggest that proton flares behave somehow differently from "ordinary" flares.

Because diffusive propagation of SEPs implies that peak proton flux is

proportional to the total number of accelerated protons, it is more appropriate to compare SEP fluxes with the fluences, rather than the peak fluxes, of flare electromagnetic radiations. Kurt (1990) has summarized work on size distributions of electromagnetic fluences and particle fluxes and finds that both types of emissions can be described in general by a differential power law spectrum with a slope of -1.45 ± 0.15. In particular, proton intensity spectra for E > 10 MeV (Belovskiy et al., 1979) and E > 25 MeV (Kurt, 1989) have slopes $\sim -1.4 \pm 0.2$, steeper than that obtained for the IMP data. From these results, Kurt (1990) concludes, contrary to Hudson (1978), that protons account for a proportionate fraction of the total flare energy budget for proton energies < 20 MeV (Kuznetsov and Kurt, 1991), i.e., all flares are proton flares.

Because the interpretation of size distributions of flare emissions in relation to SEP acceleration in flares hinges on the 20 MeV peak flux distribution and because the values obtained thus far for the power law slope of this distribution differ significantly, we determine the size distribution of IMP-8 20-40 MeV proton events for the years 1977-1983 for comparison with previous studies. For the years 1973-1989 we obtain a peak flux distribution for IMP-8 E > 3 MeV electron events. In addition, we subdivide both the proton and electron distributions into events associated with gradual and impulsive flares to see whether differences observed in such parameters as e/p ratio (Cane, McGuire, and von Rosenvinge, 1986) and the ratio of trapped to escaping protons (Cliver et al., 1989) between particle events from the two classes of flares might also be evident in their size distributions.

2. Analysis.

2.1. 24-43 MeV Protons. At these energies, the quiet background on IMP-8 is $\lesssim 2 \times 10^{-4}$ pr cm^{-2} s^{-1} sr^{-1} MeV^{-1}. We considered events with peak fluxes > 10^{-3} pr cm^{-2} s^{-1} sr^{-1} MeV^{-1} occurring from January 1977-February 1983. To discriminate against flux increases that represent only modulation of previously accelerated protons, we required an increase by a factor of five above the pre-event background to register a new event once an event was in progress. To limit the effect of propagation on the distribution, we required that the flares associated with the SEP events be located between W00-W120. If no flare was observed for an apparently well-connected event, i.e., having a fast rise and exponential decay, it was often possible to associate the proton increase with a reasonable candidate active region behind the west-limb. We rejected events with likely presumed sources > 120°. It is important to note, however, that we did not require a flare or strong candidate behind-the-limb active region to include an event in our sample. Events lacking both were included if, in our opinion, they appeared to be well-connected. Eliminating such events would bias the sample toward the larger events. In all, 92 SEP events were identified. These events were subdivided into two classes, referred to here as "gradual" and "impulsive", on the basis of the parent flare time scale. When possible, we used the soft X-ray criterion of Cane, McGuire, and von Rosenvinge (1986), whereby flares with durations $\lesssim$ 1 hr at one-tenth of the peak intensity are classified as impulsive, to make this separation. When the soft X-ray emission did not exceed 10 times the pre-event background, we used H-alpha flare duration with the same 1 hr delineator. We classified 27 of the 92 SEP events as impulsive and 54 as

gradual; 11 events could not be classified. The power law slopes obtained are as follows: all events, -1.13±0.04; impulsive, -1.13±0.09; and gradual, -1.04±0.05. The size distribution for all 92 events is shown in Figure 1 (a). The basic result of this figure is the flatter distribution of SEP peak fluxes relative to the size distributions obtained for fluences of flare electromagnetic emissions. The distribution of the impulsive events has a steeper slope than the gradual events but the difference in the slopes is within the statistical uncertainties of the measurements.

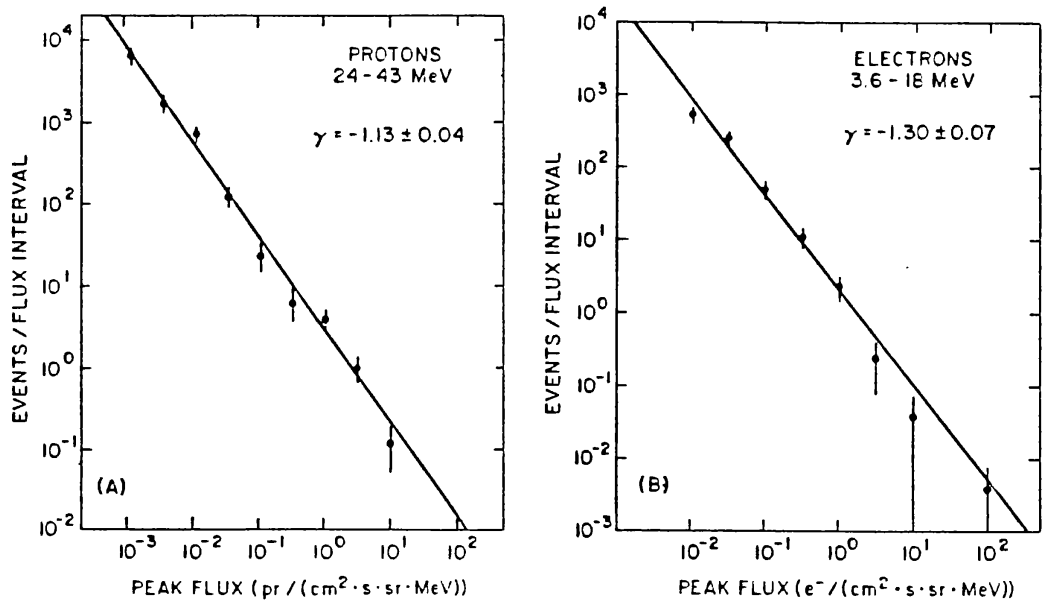

Figure 1. (a) Size distribution of peak fluxes of 92 IMP-8 24-43 MeV proton events, 1977-1983. (b) Size distribution of peak fluxes of 67 IMP-8 > 3 MeV electron events, 1973-1989.

2.2. 3.6-18.5 MeV Electrons. At these energies, the NASA/Goddard detector on IMP-8 has a quiet background level ~ 2 x 10^{-3} electrons cm^{-2} s^{-1} sr^{-1} MeV^{-1}. To register an event, we required an increase above 10^{-2} electrons cm^{-2} s^{-1} sr^{-1} MeV^{-1} and an increase by a factor of two once an event was in progress. From November 1973 - October 1989, 67 apparently well-connected (W00-W120) electron events (28 impulsive, 34 gradual, 5 unclassified) satisfied these criteria. For many events the event peak occurred during a data gap and it was necessary to extrapolate the time-intensity plot to estimate the peak. We are confident that this procedure was reasonable, because we determined the size distributions with and without the "extrapolated" cases and found no significant differences in the slopes obtained. The power law slopes of the distributions are as follows: all events, -1.30±0.07; impulsive, -1.37±0.21; and gradual, -1.20±0.08. The differential size distribution of the peak fluxes of the 67 electron events is given in Figure 1(b). If we consider the fall-off in the lowest bin of the overall distribution to result from difficulty in identifying small events, the fit to the remaining bins is -1.42±0.04, similar to what Kurt (1990) reported for the various electromagnetic fluences. Again, for limited samples, there is an indication that "impulsive" electron events have a steeper size distribution than the "gradual" events but the uncertainties

in the slopes do not allow a definitive conclusion.

3. Discussion. Insofar as size distributions may be taken as evidence for or against the existence of more than one type of flare ("proton" and "non-proton"), our result suggests the possibility of something different or additional, e.g., a coronal shock, operating in proton flares. In any case, the flatter size distribution that we find for > 20 MeV protons negates the argument that similar size distributions for flare electromagnetic and proton emissions imply a single class of flares. The fact that the power law size distribution we obtain for > 3 MeV electrons has a slope of ~ -1.3 (~ -1.4, if we discount the lowest flux bin) suggests that acceleration of the energetic electrons observed in space is more closely tied to the flare impulsive phase (since the electromagnetic emissions that define this phase have fluence distributions with slopes ~ -1.4) than is the mechanism (s?) whereby the protons observed at 1 AU are accelerated. In the same vein, there is a suggestion in our data that "impulsive" proton and electron events may follow steeper power law distributions than "gradual" events, implying that in such cases we may be observing relatively "pure" impulsive phase acceleration products.

The long durations of SEP events relative to flare emissions implies that smaller SEP events may not be observed against an enhanced background, resulting in a flatter size distribution. In addition, our factor of five requirement for "fresh injections" for the proton events may be too stringent and again might discriminate unduly against smaller events. These factors will be addressed in further study of SEP size distributions.

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