THE NATURE OF RELATIVISTIC ELECTRON INTENSITY CHANGES DURING SOLAR FLARE QUIET TIMES BETWEEN 1963 AND 1969

F. B. McDonald and T. L. Cline
Goddard Space Flight Center, Greenbelt, Md.

and

G. M. Simnett
Physics Department, University of California, Riverside, Ca.

Abstract

Time variations of the 3-12 MeV interplanetary electron intensity, observed by the IMP-1, -3 and -4 spacecraft between 1963 and 1969, have been studied in detail. Apart from solar flare effects, there are five distinct periods when the electron intensity has undergone a series of increases, and these are strongly correlated with solar rotation. For only one period, in 1966, there is evidence that the intensity changes are recurrent solar electron events. The other intensity increases are a separate phonomenon, and are strikingly anticorrelated with increases in the low energy solar proton intensity. The electron energy spectrum during those non-solar, or "quiet-time" increases is typically represented by $dJ/dE \approx k\ E^{-2.0 \pm 0.25}$, similar to the galactic electron spectrum. Correlations of the electron intensity with the Deep River neutron monitor show that typically the neutron monitor is increasing through the period of a quiet-time electron increase. The magnitudes of the quiet-time electron intensity increases do not have a large variation, but are between about two and about five times the galactic background intensity seen at the earth. There are, in addition, Forbush decreases in the electron intensity frequently coincident with those in the neutron monitor rate. We conclude that these characteristics all support the hypothesis of a galactic origin for the electrons observed during quiet-time increases.

1. Introduction

The study of the low energy galactic cosmic-ray electron component is of fundamental importance to a variety of topics. Unfortunately, the effects of solar modulation and the presence of solar electrons greatly distort the low-energy galactic electron spectrum. A detailed study of the temporal intensity variations may be one possible means of separating the galactic and solar components, and it should also thereby provide information on the modulation of MeV electrons. With the availability of sophisticated particle detectors on spacecraft operating beyond the magnetosphere, it has been possible to make detailed observations of low energy interplanetary particles over a significant portion of a solar cycle.

An examination of the nucleon and electron data over wide energy intervals reveals two spectra which appear to be similar, each apparently composed of a two-component structure with a power law at high energies, a plateau or minimum at medium energies, and finally a sharp rise at the lowest energies. Thus, the structure observed in both spectra might appear to be produced by solar modulation. However, the low energy components observed in the two spectra cannot both be explained as of solar origin in such a straightforward manner. In fact, the data to be presented suggest that the origin of the electron intensity enhancement is quite different from that producing the proton increases.

2. Observations

The temporal changes of the 3-12 MeV electrons observed from November, 1963 to September, 1969 can be grouped into five categories:

1) Flare-associated solar electron events: In general, these display the same characteristics as the accompanying solar proton events.

2) Co-rotating Solar Electron Increases: These appear to occur infrequently in the MeV region. They coincide with geomagnetic effects and with roughly simulteneous low energy electron and proton increases.

3) Forbush decreases: These are generally similar to those observed with high-latitude neutron monitors, except that the recovery phase for electrons has a different time profile.

4) The long-term modulation of low energy electrons: The existence of this phenomenon appears likely, but is difficult to establish because of the varieties of large-amplitude short-term intensity variations.

5) Quiet time increases: This new phenomenon is unique to the electron population above 1 MeV. The increases last for periods from a few days to two weeks and can display a 27-day recurrence. The intensity may increase as much as a factor of five above the minimum quite-time level at 1 A. U. The energy spectra of the increases above background are similar to that determined for the galactic component. These events are strikingly anticorrelated with low energy (few-MeV) proton events.

The implication of this picture of interplanetary electron phenomena, including the quite-time increases, the Forbush decreases and the suggestion of an eleven-year modulation, is that the galactic component probably dominates most of the time.

3. Experimental Technique

Observations of the interplanetary 3 to 12 MeV electron intensity have been made with identical detectors on-board four eccentric-orbiting IMP satellites; data were used for analysis from the following time periods, and over the following altitude intervals:

IMP I:	November 27, 1963 - May 5, 1964,	125000 to 193000 km	(apogee)
IMP III:	May 30, 1965 - May 4, 1967,	125000 to 250000 km	"
IMP IV:	May 24, 1967 - March, 1969,	100000 to 216000 km	"
IMP V:	June 21, 1969 - September 24, 1969	100000 to 177000 km	"

The energy loss detector in each consists of a 0.1 cm thick x 5.08 cm diameter CsI (Tl) crystal which is operated in coincidence with a 2 cm thick x 5.08 cm diameter CsI (Tl) crystal, used as a total energy detector for stopping particles. A plastic anticoincidence guard counter surrounds the total energy detector.

The problem of normalizing the data from four different satellites operating over lengthy periods of time with no overlap involves primarily corrections for gain and background changes. The minimum-ionizing line and the end point of the stopping proton distribution provided methods for measuring gain changes, and the background contamination was subtracted using the method described by Simnett and McDonald (1969). A normalization was thereby made possible between time periods covered by the different IMPs. A plot of the daily electron counting rate in a common energy region over the periods treated with this analysis is shown in Fig. 1. The errors on the points are approximately constant and are therefore not individually shown. (The IMP-IV and IMP-V satellites incorporated an additional solid state element, used to obtain daily averages of 3.3 - 5 MeV protons; these data do not reflect the quiet-time level, but the fluctuations are representative of the intensity changes. The degree of anticorrelation of the proton increases with the quiet-time electron increases is significant in the present analysis.)

4. Interpretation of Results

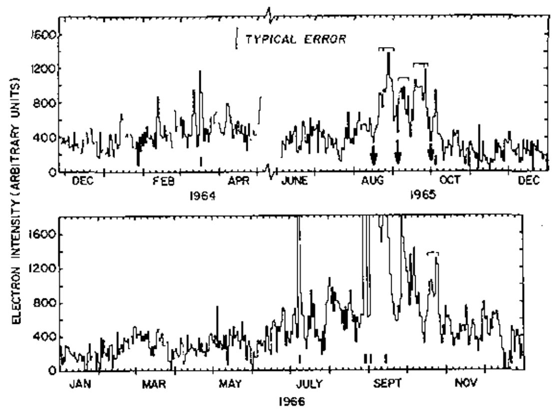
It is evident from Fig. 1 that the electron component shows many types of variations. The flare-associated and recurrence electron increases, the Forbush decreases and possible eleven-year variation are extensions of known particle phenomena. However, there are some 18 or 19 increases occurring during the several-year observing period that appear to represent a new phenomenon. These tend to occur during relatively undisturbed times, so we have labeled them "quiet-time increases". They have the following properties:

(1) They represent a factor of 2 to 5 increase in the 3-12 MeV electron intensity and last about 3 to 14 days. The time history is symmetrical and markedly different from those in flare events. (2) The energy spectra of the increases are in general of a form much closer to the $E^{-1.75}$ obtained when the intensity was relatively constant than to the E^{-3} to E^{-5} of solar events. (3) There is a remarkable anticorrelation with low energy co-rotating proton events. (4) The increases tend to occur during periods of rising neutron monitor intensity. (5) The available evidence suggests there is not a strong dependence on solar activity. (6) The increases frequently display a 27-day periodicity. (7) In general, the increases are contained within a single interplanetary magnetic sector.

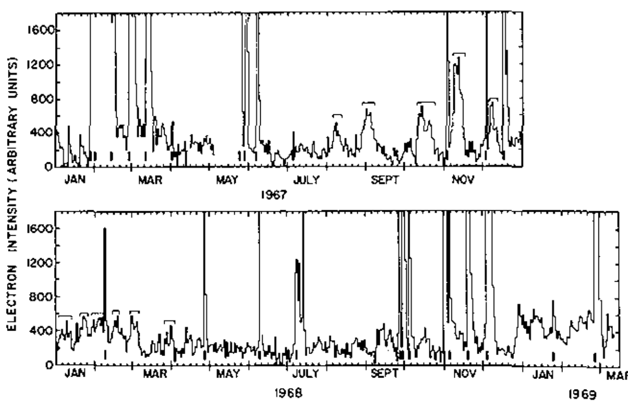
Sixteen of the quiet time increases were observed in three groups: 4 in early 1964, 3 in 1965 and 9 during an 8 month period in 1967 to 1968; there was only a single increase in 1966. The Dec. 1968 - Jan. 1969 period also displays several increases of a somewhat different appearance, as discussed later.

The first series of quiet-time increases, observed with IMP-I in early 1964, occurred with peak intensities at 27 $\pm$ 1 day intervals on

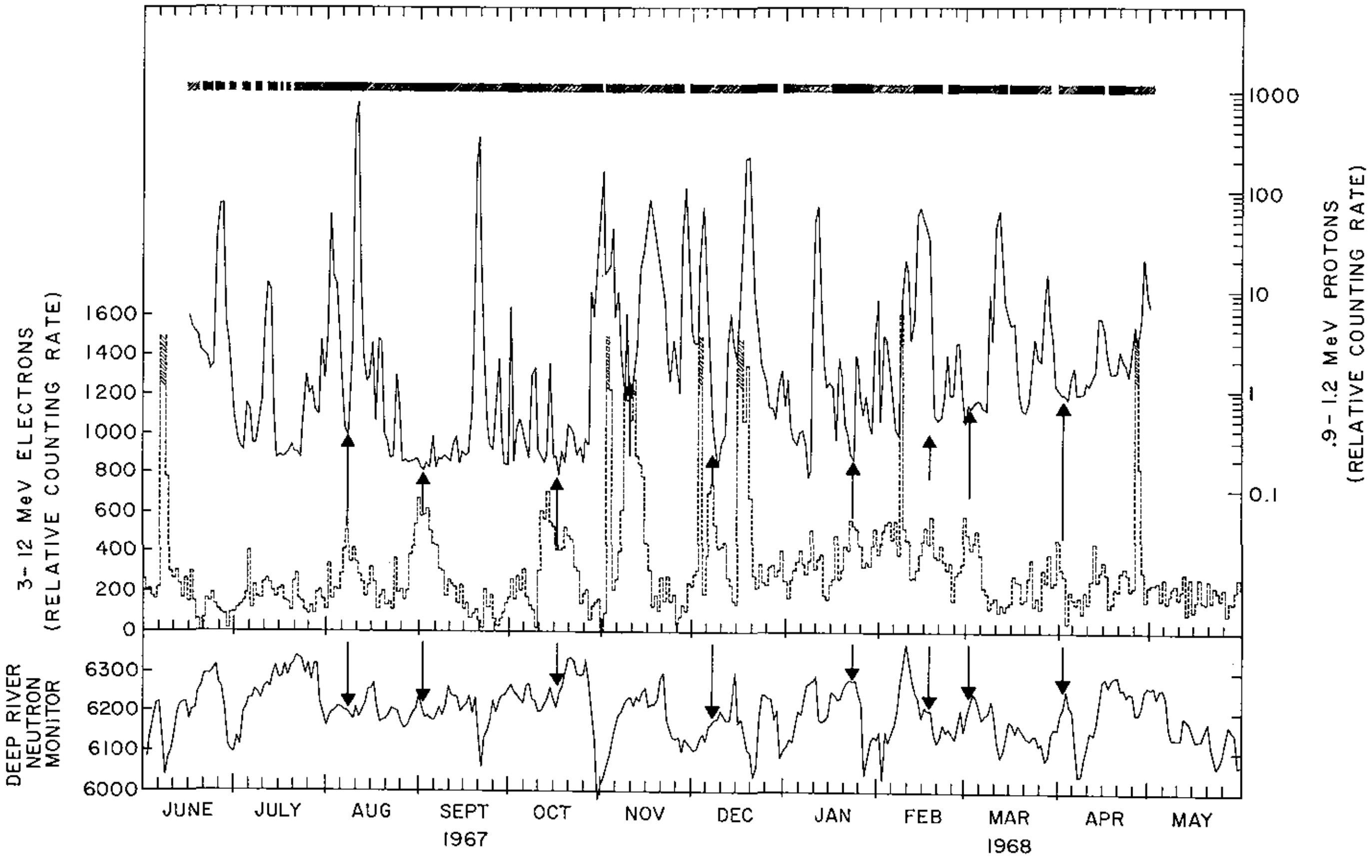
February 12, March 11, April 7, and May 3, and possible another in mid-January. (These are the least well defined, due to a lower data rate on that satellite.) This behavior was pointed out originally by Cline et al. (1964), as evidence that the electrons were of galactic or solar origin and not secondaries generated locally in the vicinity of the detector. The University of Chicago experiment on IMP-I observed a series of 4 co-rotating streams of MeV protons. These were contained within a single, positive recurrent interplanetary magnetic sector (Ness and Wilcox, 1965), displaced almost 180° from the electrons.



The next series consists of three well-defined events extending from mid-August through late September, 1965. Two of the events are spaced 27 days apart and the third is interspaced between them. There were three low-energy proton events observed with the University of Chicago detectors, on August 16, September 3, and September 30, and a small flare-associated event on October 4, 1965. The co-rotating proton events are indicated by arrows in Figure 1. Again, the anti-correlation between quiet-time electron events and the low-energy proton increases is most striking. There is no strong correlation either with the neutron monitor data (except for a general increase in the neutrons during the events) or with the direction of the interplanetary magnetic field.



Some nine quiet time increases were observed with IMP-IV between August 1967 and March 1968; they are the most striking of all, and are shown in Figure 2. The first two events, in early August and September are approximately 27 days apart. The next event is centered on October 16, and lasts for some 12 days. The next event is centered on October 16, and lasts for some 12 days. From Nov. 5 to 15, there is a fourth event. (A moderate flare-associated event had occurred on November 2, but the electron intensity had returned to background by November 4.) This quiet time event occurs some 24 days after the October increase. Like the other events in this series the electron peak occurs at a minimum in the flux of low energy protons, although there is some overlap between the declining phase of the electron increase and a low energy proton event. Twenty seven days later the same pattern is reproduced. After a flare event early in December, there is another quiet time increase. Four more small increases occur during the first three months of 1968. Detailed examination shows that again for these nine events the low energy protons and quiet time increases anticorrelate. In almost every case the centroid of the quiet time increases coincides with a minimum in the MeV proton distribution and most of the quiet time increases occur during periods when the neutron monitor rate is increasing. A comparison of the average profile of the five quiet time increases occurring between August and November with the averaged neutron monitor data, shows an essentially monotonic cosmic-ray increase throughout the electron increase with a later decrease 8 to 9 days after the electron maximum.



The large quiet time increases in 1965 show the same behavior. If the quiet time electron increases are galactic in origin and are visible because of a temporary change in the modulating mechanism, it might also be expected that the galactic protons also respond to the temporary change. It appears that there is a one week phase lag between the electron and nucleon components.

There are two additional periods which also may contain quiet time increases. A single increase takes place from October 15 to 27, 1966; it appears to be essentially identical to the November 1967 event discussed above. The second period of interest is the interval of December 1968 to February 1969. On December 27 there is a very small event, consistent with an origin on the non-visible disc of the sun.

There is a second increase extending from February 7-15, having an electron energy spectrum of the E^{-2} form, consistent with a quiet time increase. Starting on February 5 there is a steady increase, with some structure, that builds up to the large event of February 25. The energy spectrum suggest that the February 7 peak is a quiet time increase, it also follows some 27 days after the January event. However, the spectral data of the various structural details during this month are not conclusive.

5. Discussion

The low energy electron data suggest that two processes may be occurring in the modulation of galactic particles. The quiet-time increases suggest a sudden increase that takes place on the order of several days, while the 11-year modulation extends over a far larger time scale. Furthermore, during the quiet-time increases, there are no corresponding large increases in the low energy (20-80 MeV) galactic cosmic rays, and only a positive trend is evident in the neutron monitor. One possible resolution of this problem has been suggested by Fisk and Van Hollebeke (1971) who propose that the electron increases are not a result of the variation of electron modulation but rather an increase in the number of electrons that penetrate into a modulating region. One would expect a decrease in the peak intensity of quiet-time increases as solar activity increases if such a two-step process is involved, and this is qualitatively what is observed. In fact, not only is there a decrease in the peak amplitude as one goes from 1965 to 1969, but also the likelihood of occurrence seems to be less at solar maximum.

The question then arises as to whether the observed electrons are "interstellar secondaries" produced by the "knock-on" and $\pi \rightarrow \mu \rightarrow e$ processes or whether one is also observing primary electrons. During the quiet time increases, the observed peak intensity at 3 MeV was 5 times the calculated secondary interstellar intensity (see, e.g. Abraham et al., 1966). This suggests strongly that one must also have galactic "primary electrons" present in the MeV interplanetary electron component. It also makes difficult the determination of the energy dependence of the total modulation of galactic electrons in the inner solar system, or, conversely, of their intensity in the interstellar region.

6. References

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