

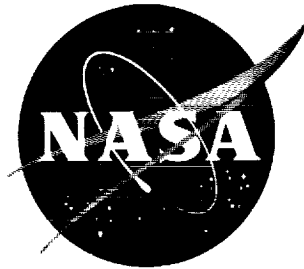
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# TECHNICAL NOTE

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**SEPTEMBER 26, 1960 SOLAR COSMIC RAY EVENT**

C. E. Fichtel, D. A. Kniffen  
and K. W. Ogilvie

Goddard Space Flight Center  
Greenbelt, Maryland

12405

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C. E. Fichtel, D. A. Kniffen

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K. W. Ogilvie

*Goddard Space Flight Center*

## SUMMARY

Type IV radio emission is thought to be the most important observable characteristic of solar flares producing high energy particles. We show here that solar cosmic ray particles arrived at the earth on September 27, 1960 following a small flare accompanied by a type IV burst of short duration. Apart from their magnitude, the characteristics of this event do not differ essentially from those of larger events.



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## INTRODUCTION

Considerable attention has been directed toward the study of major solar cosmic ray events, especially during the present solar cycle (Reference 1). These major events have been characterized by integral fluxes of protons above 80 Mev, which were of the order of 100 times the cosmic ray background, and by large, easily observable, cosmic noise absorption—"polar black-outs"—as detected by a ground-level riometer. Increases in the counting rates of sea-level neutron monitors indicate that in some events the proton energy spectrum has a large high energy component. It is known that essentially all major solar cosmic ray events follow major flares which are associated with type IV radio bursts (References 2, 3, and 4), but not all type IV radio emissions have been followed by major solar cosmic ray events. It has been suggested by Hakura and others (References 5, 6, and 7) that type IV radio emissions are due to the synchrotron radiation of electrons accelerated in solar events in which protons were also being accelerated. This naturally suggests the possibility that solar protons, presumably in much smaller numbers than in the large events, also follow small type IV radio bursts.

To assist in determining whether or not type IV radio emissions are related to solar cosmic ray events in general, and to study the properties of any particles that might be present in a smaller event, a sounding rocket carrying nuclear emulsions and counter instruments was fired on September 27, 1960, at 1444 UT, from Churchill, Canada, into an event of the aforementioned smaller type.

## DESCRIPTION OF THE EVENT

Table 1 lists the flares that were observed during the period September 24-September 27, 1960. One of these flares—beginning at 0525 UT and ending at 0605 UT on September 26, 1960—is particularly interesting since it is the only one of the group which had an associated type IV radio burst. It was reported by CSIRO (Sydney), which also reported type III and type II bursts at about the same time. The time interval during which the type IV continuum was observed was relatively short, 0554 to 0611 UT September 26, 1960.

\*This report has been published in substantially the same form in *J. Geophys. Res.* 67(10):3669-3672, September 1962.

Table 1  
Solar Flares September 24 to 27, 1960  
(Importance 1+ or above).

Date (1960)	Beginning of Flare (UT)	Class of Importance	Plage Number	Approximate Solar Coordinates (degrees)	Ionospheric Effect
September 24	0714	1 to 1+	5863	S21 W01	
	0923	1 to 1+	5863	S20 E01	
	2116	1 to 2+	5863	S20 W10	
	2304	1+	5866	N26 E19	
September 25	0759	3	5866	N26 E09	
	1246	1 to 2	5863	S18 W10	
	1932	2- to 2	5866	N27 E06	
September 26	0525	1 to 2+*	5858	S21 W64	Slow S-SWF
	1350	1 to 2	5858	S21 W63	Slow S-SWF
September 27	1250	1 to 2-	5863	S13 W24	
<p style="text-align: center;">There were no flare patrol observations during the following intervals:</p> <p style="text-align: center;">September 24: 0245 UT - 0300 UT  0515 UT - 0600 UT  1315 UT - 1330 UT  September 25: 0200 UT - 0345 UT  0415 UT - 0500 UT  September 27: 0130 UT - 0500 UT</p>					

\*Classified by Tashkent as 2+ and by Mitaka as 1.

The 0525 UT flare had several other characteristics which have been shown to be related to solar cosmic ray events: (1) There was a S-SWF (Sudden Short Wave Fadeout) of intensity 2+. (2) The plage group in which the flare was located was reasonably well developed and had one penumbral area which was large enough to classify it, according to the Anderson criterion (Reference 8), as a region likely to produce a solar cosmic ray event. (3) The same plage group had been seen on a previous rotation of the sun. Dodson (Reference 9) has shown that the second rotation is the most probable one for the occurrence of a major polar cap absorption event.

The small amount of absorption detected by riometers on September 26, 27 and 28, 1960 (References 10 and 11) has features characteristic of polar cap events. The absorption began at Churchill about an hour after the type IV radio burst and was generally greater during the day than at night, always remaining greater than zero. However, the sunrise onset and sunset recovery was not uniformly clear at all stations.

## EXPERIMENTAL RESULTS

Since a discussion of the Nike-Cajun payload system employed in the Solar Beam Experiment, the flight characteristics of the rocket, and the general method of reducing the data derived from the



nuclear emulsions and particle detectors are presented fully in the papers by Davis (Reference 12), Biswas (Reference 13) and Ogilvie (Reference 14), only a brief statement will be given here. The nuclear emulsions are exposed to the ambient radiation for an equivalent period of about 135 seconds (Reference 12). The corrections to the emulsion results for ascent, descent, background, measurement uncertainties and attitude of the rocket are relatively small (References 10, 11 and 12) and can be made with a combined uncertainty of about 10 percent. Therefore, a large fraction of the error in individual data points is statistical. The proton energy spectrum obtained is shown in Figure 1. The low energy cutoff of the kinetic energy at 13.5 Mev is determined by the material between the depth in the nuclear emulsions at which the energy measurements were made and the ambient

radiation, since the threshold due to the magnetic field is much lower than this at Churchill. The high energy limit is set by the limited collecting time and the small flux of particles. For purposes of comparison in the low energy region, essentially identical firings were made from Churchill, on June 6, 1960 and December 10, 1961, during geophysically quiet times. The September 27 proton flux in the 13-50 Mev interval is at least twenty-five times normal.

We now turn to a discussion of the counter instrumentation results. An unfortunate power failure in the telemetry recorders during the flight of September 27 has prevented a full analysis of the counter observations. It is, however, possible to present some information, which is, of necessity, of low accuracy. In Figure 1, the solid triangle at 30 Mev represents the results of the geiger counter measurement. It must be emphasized that these results, in contrast to the usual practice, are not independent of the emulsion results. The slope of the energy spectrum measured by means of the emulsions has been used to compute corrections in the range for which it is applicable. The points shown at 4.5, 2.8 and 1.8 Mev represent the results of the scintillator measurements. We were unable to employ our usual method of ratios, but the fortunate circumstance of the steep spectrum allows approximations to be made. Their effect is reflected in the large errors, but the results demonstrate that the spectrum undoubtedly curves over at low energies in the region of 10 Mev. If the spectrum at higher energies had persisted down to a few Mev the rates observed by the scintillators would have been at least an order of magnitude higher than observed.

Later measurements, made at the end of the event of November 15, 1960 when the magnetic field had returned to its normal value, were consistent with a threshold of  $4.5 \pm 0.5$  Mev at Churchill (Reference 14).

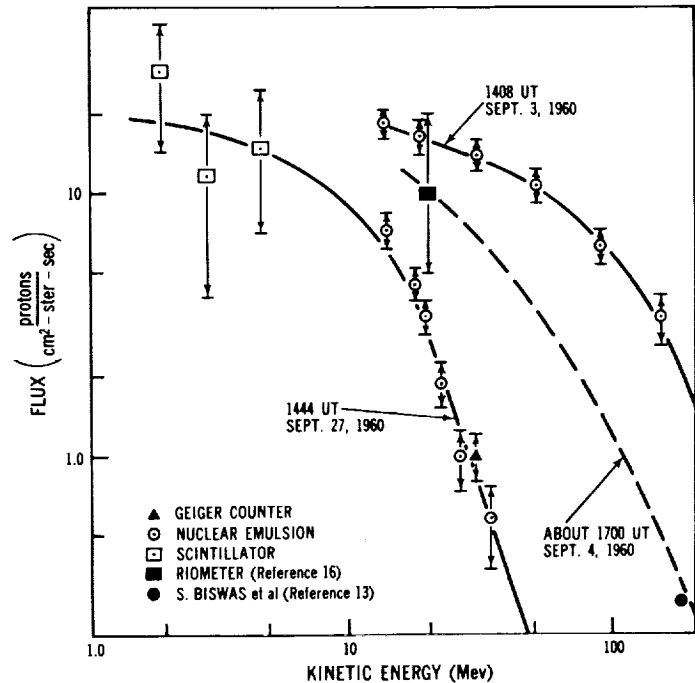


Figure 1 — Primary Proton Energy Spectrum

On the 27th of September 1960, the magnetic conditions immediately before the rocket firing were fairly disturbed (Reference 15). There was a magnetic storm with a small initial impulse which began at 1930 UT on the 26th and ended at 1100 UT on the 27th. The magnetic threshold was, therefore, 4.5 Mev or less at the time. Thus we may say with certainty that the integral spectrum curves over in an energy region well above the threshold.

If a curve of the form  $dj/de = N_0/E^{\gamma(E)}$  is fitted to the data points,  $\gamma$  is found to be  $3.6 \pm 0.6$  at 25 Mev. The slopes of the spectra found in other events are presented in Table 2. Since this quantity varies with time we have quoted results of observations taken as close to the sametime after the corresponding flare as possible. The slope of the September 27, 1960 differential proton spectrum at 25 Mev, about 33 hours after the flare, is seen to be somewhat steeper than that of the November 12, 1960 or the November 15, 1960 proton spectra at comparable times. The slope of the September 3, 1960 proton spectrum is seen to be fairly small relatively early in that event. Although no data was available from this laboratory late in the event, an approximate integral energy spectrum about forty hours after the September 3, 1960 flare was constructed by using the results of Biswas (Reference 13) at high energies and the estimated flux at 20 Mev based on riometer data (Reference 16). The detailed energy spectra for these flights are compared in Figure 1.

Table 2  
Slope of Differential Energy Spectra  
for  $E = 25$  Mev

Event	Time from Beginning of Associated Flare (hours)	Solar Coordinates (degrees)	Slope
September 3, 1960	14	N20 E87	$0.6 \pm 0.3^*$
September 26, 1960	33	S21 W64	$3.7 \pm 0.6$
November 12, 1960	27	N26 W5	$2.1 \pm 0.3$
November 15, 1960	42	N26 W35	$2.1 \pm 0.3$

\*A value of 1.3 is obtained 40 hours after the flare by the method discussed herein, but this number is very uncertain.

The fact that the energy spectrum of the September 27, 1960 event is steeper than the other three measured should not be taken to mean that this event is different from all others. For example, consider the August 29, 1957 event whose energy spectrum late in the event was also very steep. The flux at 20 Mev as deduced from riometer absorption was a few hundred particles/cm-ster-sec, yet Anderson (Reference 17) saw no detectable increase at balloon altitudes where the energy threshold was 100 Mev. The slope of the differential energy spectrum of this latter event between 20 and 100 Mev must then have been of the order of 6 or more.

## CONCLUSION

We have shown that, in at least one case, solar cosmic ray particles arrived at the earth following a relatively small flare, but one accompanied by a short duration type IV radio burst. Further, the

September 26, 1960 event fits well into what seems to be a developing pattern for solar cosmic ray events. These events normally follow flares accompanied by type IV radio emission; their proton spectra steepen at high energies and have a slope of the order of 1 to 6 in the ranges of tens of Mev late in the event. These general features will be elucidated by means of the additional data which will be forthcoming from the experiments of Davis, McDonald, Van Allen and others on Explorer XII, which was launched in August of 1961.

## ACKNOWLEDGMENTS

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