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II-3B-16. Rocket Observations of Solar Protons during the November 1960 Event

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Three Nike-Cajun rockets were fired from Fort Churchill during the solar proton event which took place on November 12, 1960. The geiger counter and scintillation counter instruments were carried to a height of 130 km, and were above an altitude of 90 km for a period of greater than 150 secs. The rockets also carried nuclear emulsions. The times of firing and other details are given in Table I below.

From these times it will be seen that the first shot occurred towards the end of the period when the neutron monitor rate was approximately constant, after its initial increase. The second shot occurred some time after the second increase, when the rate was decreasing steadily. The third was made when the neutron monitor rate had decreased almost to normal.

Table I.

Rocket Nb	Firing time U. T.	Time from Flare	db absorption Ft. Churchill riometer	Recovery of Emulsion
1024	1840/12th	5 hrs. 27 m.	12-6 db	yes
1015	2332/12th	10 hrs. 19 m.	4-6 db (night)	no
1016	1603/13th	26 hrs. 50 m.	14-9 db	yes

From the response of the detectors we can find the spectra of the protons incident at the top of the atmosphere for these three times. Thus we have a spectrum of the protons which diffuse out of the trapping region as it approaches the earth, rocket 1024, and of those contained in the trapping region at two later times. We can also find the angular distribution of the protons at the top of the atmosphere.

In Fig. 1 we show the magnetic zenith angular distribution found for flights 1024 and 1016 for the CsI scintillation counter (step 5 sensitive from 1.8 Mev to 160 Mev). This shows the assumption of isotropy to be well fulfilled in the upper hemisphere, for angles between 25° and about 90°. The fall-off outside the upper hemisphere is not sharp, due to the ±15° opening angle of the detector. The flux at angles greater than about 110° is due to particles scattering below the apparatus, and also those being mirrored by the magnetic field and returning from below. The angular distribution for the ZnS scintillator, shows more variation. Isotropy just above the atmosphere does not of course mean isotropy in space away from the earth's magnetic field.

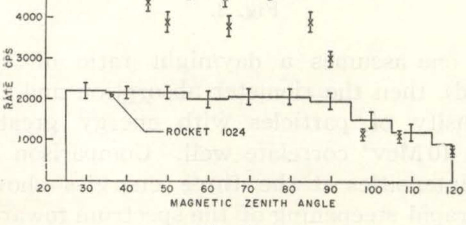

Fig. 1.

The integral proton energy spectra found by analysis of the first three flight records are shown in Fig. 2. The shape of the spectra are generally similar, with a gradual lessening of slope in the region down to a few Mev, and an increase in flux at even lower energies.

In the diagram of the spectra, the point marked "Explorer VII" indicates the flux value given by Lin (1961), divided by 4π, obtained from the Explorer VII results. The satellite was at an altitude of 877 km, 44° latitude, and 300° longitude at the time of

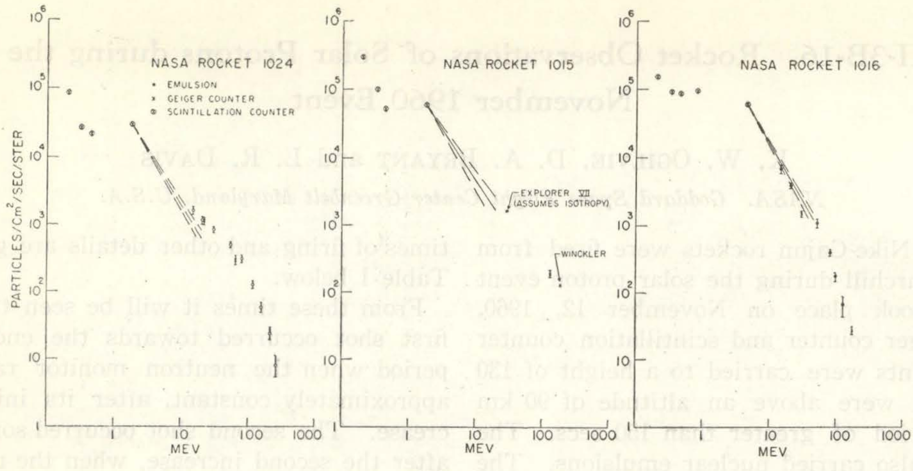

Fig. 2.

firing of rocket 1015; the magnetic field line passing through this point crosses the equator at about three earth's radii. The point marked "Winckler[9]", is derived from the observations of Winckler's group at Fort Churchill during the event.

Balloon observations have previously indicated spectra with exponents in the range 4—5, above about 100 Mev. (Winckler, 1960). It is now clear that extrapolation of the balloon spectra to low energies is not a satisfactory procedure. The intensity found by balloon measurements at the time of rocket 1015 do however agree with our measurements at the corresponding energy.

The analysis of the scintillation counter results in the energy region above 2 Mev were made by assuming a power-law spectrum, and introducing a cut-off at low energies when necessary. This procedure gives the best straight-line fit to the data, and comparison with the completely independent emulsion results obtained by Fichtel, and with our geiger counter results shows good agreement. It is thus possible that these cut-offs represent the magnetic thresholds at Fort Churchill at the times of firing of the rockets. The Quenby and Webber cut-off for Fort Churchill is 5.8 Mev.

We must now consider the rising portion of the spectrum below 0.4 Mev. Auroral absorption was not shown on the Churchill riometer at the time of any of the shots, but at the firing times of 1024 and 1016 the instrument was almost off scale and not very sensitive. Proton intensities of similar order of magnitude and spectrum have been observed in and near auroras by (Davis *et al*, 1960), (McIlwain, 1960) and recently by McDiarmid *et al*.

In Fig. 3 we show the neutron monitor rate (Steljes *et al*, 1961), the Fort Churchill riometer absorption, the intensity at three energies, and ΔJ, the excess of intensity at 200 Kev over that at 2 Mev, plotted against time.

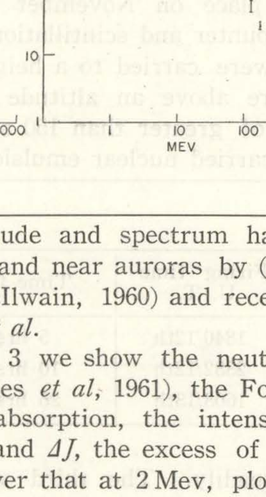

Fig. 3.

If one assumes a day/night ratio of 3 : 1 (Reid), then the riometer absorption and the intensity of particles with energy greater than 10 Mev* correlate well. Comparison of the intensities at the three energies shows the rapid steepening of the spectrum towards high energies which has been previously noted by many observers. The figure also shows that the riometer absorption is predominantly produced by particles in the range between 10 and 100 Mev.

ΔJ underwent a large increase between the times of rockets 1024 and 1015, when the earth was supposed to be entering the trapping region, and a considerable decrease again by the time of firing of 1016.

This experiment cannot clearly determine whether the additional very low energy particles represent a simple extension of the spectrum of particles from the sun in which case the cut-offs observed do not correspond to threshold rigidities, or whether they are a separate phenomenon. If they are then this suggests that we are observing the high energy tail of the distribution of protons responsible for the magnetic disturbances, and that these are not excluded by the threshold. The rocket observations cited (Davis *et al*, 1960), (McIlwain, 1960), (McDiarmid) strongly suggest that these protons are present in some quantity for a high proportion of the time at Fort Churchill.

Supporting the idea that the additional low energy particles are associated with the magnetic storm is the fact that at 0.2 Mev, the rectilinear travel time from the sun is 7 hours, so that such particles emitted by the flare could not have been observed by rocket 1024. By the time of rocket 1015, when a very large intensity of such particles was observed, the particle path length would have to have exceeded the direct path length by less than 50%. This is an interesting contrast to the behavior of the intensity at 10 Mev, which was still rising at 26 hours after the flare, more than twenty times greater than the time for rectilinear passage from the sun.

Again, due to the complicated nature of the event, one cannot exclude the possibility that the lowest energy particles were produced by the flare, probably of important 3+ and accompanied by an SID of duration $4^1/_2$ hours and type IV radio emission, which occurred at 0316 U.T. on the 11 Nov. This flare did not produce a neutron monitor increase or an effect on the riometer.

Conclusions:

To summarize the conclusions from these rocket flights,

(1) The spectra of protons at all times has a generally similar form and cannot be adequately represented near the earth by an extrapolation of the power law appropriate at ballon altitudes. This does not mean that the spectra observed here are appropriate at large distances from the earth.

(2) The particles are isotropic in the upper hemisphere just above the atmosphere.

(3) The observed low energy particles are either the high energy part of the magnetic storm distribution, or, less likely, are the results of the modification of the initial spectrum by the expansion of the solar plasma cloud in which the trapping occurs, or a combination of both. The most reasonable interpretation is that the observed cut-offs represent the magnetic thresholds at the time, that the low energy particles enter the field by another mechanism, and that the shape of the spectrum above the cut-off is influenced by the expansion of the trapping region.

A full account of these experiments will be published in the Journal of Geophysical Research.

Discussion

Roederer, J. G.: Your third shot was done at a time, at which we claim no high energy solar particles were present anymore. I wonder how this fits into your result on spectra of low energy particles.

Ogilvie, K.W.: There was a large change in spectral slope during the event and these observations are not incompatible with our data taken about one-day after the flow.