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# II-3B-11. Geomagnetic Storm Effect on the Solar Cosmic-Rays in November 1960 and Their Propagation Process in the Interplanetary Space

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The cosmic ray unusual increases of November 12 and 15, 1960 are investigated by using the cosmic-ray neutron data from the stations distributed over the world, especially in the Arctic and the Antarctic regions. The gradual rise of the 1st hump of November 12, 1960 is explained by both the geomagnetic modulation in the initial phase of the geomagnetic storm and the trapping of the solar cosmic ray particles by the solar magnetic cloud responsible for the geomagnetic storm. The 2nd hump on November 12 is due to the geomagnetic modulation effect in the main phase of the storm combined with the supply of low energy particles trapped by the cloud. The primary energy spectrum of the differential intensity for flare increases on November 12 is obtained as $KE^{-\gamma}$ with $\gamma=6$. In case of the November 15 event, the difference of the onset time in different localities suggests that the first incidence of the solar cosmic ray particles came from the direction of geomagntic latitude 5°—30°S and next, about one hour later, they came from the opposite direction of 5°—30°N.

## §1. Main Features of the November 1960 Events

Main features of the cosmic ray events in November 1960 are summarized as follows*:

(I) The November 12, 1960 event

1. Two humps of cosmic rays were observed within a few hours, when only one acceleration evidence of the solar cosmic rays in the flare region was shown from the solar radio noise observation.

2. Both of them occurred during the geomagnetic storm, *i.e.*, the 1st hump occurred during the initial phase and the 2nd hump occurred in the main phase of the storm. This fact leads us to suppose some geomagnetic storm effect on the solar cosmic rays.

(II) The November 15, 1960 event

1. The rise time (that is, the difference from the onset time of the solar flare to the time at which maximum intensity of cosmic rays was observed) is largely different among the different stations.

2. The onset time at Syowa Base is early by about one hour, compared with other stations*.

3. This event just occurred during the development of a large Forbush decrease. So, the difference of the rise time is supposed to be due to the interplanetary magnetic field responsible for the Forbush decrease.

## §2. The Geomagnetic Modulation Effect on the Solar Cosmic Rays on November 12, 1960

It is our purpose in this section to study the geomagnetic modulation effect on the solar cosmic ray intensity on November 12, 1960 during the geomagnetic storm. From the time sequence of the cosmic ray event and other related solar and terrestrial phenomena, it is supposed that some of the low energy particles of the cosmic rays emitted from the sun are trapped by the solar cloud responsible for the geomagnetic storm[3] and

* Descriptions of details were already given in the previous papers[1,2].

* Mawson and Ellsworth stations show nearly the same onset time as in Syowa Base.

so they cannot reach the earth immediately, but they are supplied to the earth from the solar cloud when the earth is surrounded by the cloud to produce the geomagnetic storm, and that the other part of the solar cosmic rays impinged to the earth directly from the sun through the cloud.

Now we suppose the energy spectrum of the solar cosmic ray particles as $j(E)=KE^{-\gamma}$ when they are emitted from the sun. From the viewpoint mentioned above, the energy spectra of the solar cosmic ray particles trapped or supplied by the magnetic cloud are obtained. The latitude effect of the depressed part of the solar cosmic ray intensity for the lst hump due to the shift of the magnetic cutoff towards the higher side during the initial phase of the geomagnetic

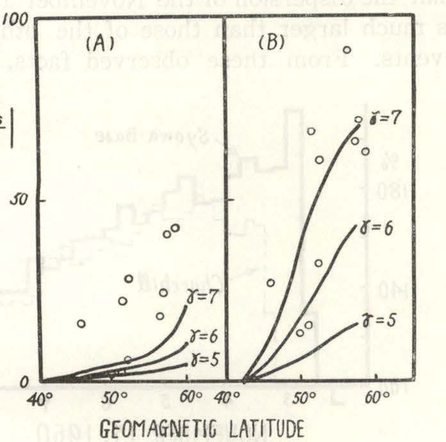


Fig. 1. Computed latitude dependence of solar cosmic ray intensity assuming several values of the exponent $\gamma$ of the power law spectrum. (A) is for the initial phase and (B) for the main phase of the geomagnetic storm. Points are estimated from the observed data at different stations.

storm is shown in Fig. 1-(A) and also the enhanced part for the 2nd hump due to the shift of the cutoff towards the lower side during the main phase of the storm in Fig. 1-(B), where the solid lines are the theoretical curves of the geomagnetic modulation only and circles show the values obtained from the observed data. The theoretical curves were obtained by assuming the actual horizontal intensity change of the geomagnetic field as $+10\,\gamma$ and $-100\,\gamma$, respectively*. As for the observed values, the depression of the lst hump is deduced by assuming the decay curve subjected to the same exponential law as in the November 19, 1949 event, being the decay time constant of 180 minutes, and also assuming the time of maximum intensity for the lst hump as 1500 UT. We see that the theoretical curves in Fig. 1 are not necessarily in good agreement with the observationl values.

Supposing that the differences between observed values and theoretical curves in Fig. 1 are due to the trapping effect by the magnetic cloud, the latitude dependence of the trapping particles is deduced from considering that the theoretical curves tend to zero at high latitude. Fig. 2 gives one example

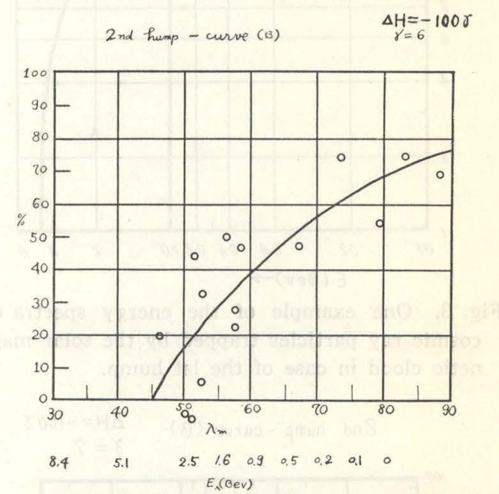


Fig. 2. One example of latitude dependences of the differences between the observed points and the theoretical curves, for $\Delta$H$=100\gamma$ and $\gamma=6$.

for the 2nd hump. From this latitude dependence, we obtain the energy spectra of the particles trapped by the magnetic cloud. One of them, for $\Delta H=+10\gamma$ and the power of the spectrum $\gamma=6$, is given in Fig. 3. Similarily, one of the energy spectra of the supplied particles from the magnetic cloud to the earth is shown in Fig. 4, for $\Delta H=-100\gamma$ and $\gamma=7$.

* The theoretical curves in Fig. 1-(A) calculated for the enhancement of the geomagnetic field are a little different from those in reference 1, where they were calculated for the geomagnetic field change $+60\gamma$ which is fairly larger than the actual data.

From a comparison of Figs. 3 and 4, it is shown that the energy spectrum of the particles trapped by the magnetic cloud is nearly equal to that of the supplied particles. It is natural that the value of $\gamma$ increases with time from 6 to 7 because the high energy particles are easy to escape from the vicinity of the earth, rather than low energy particles.

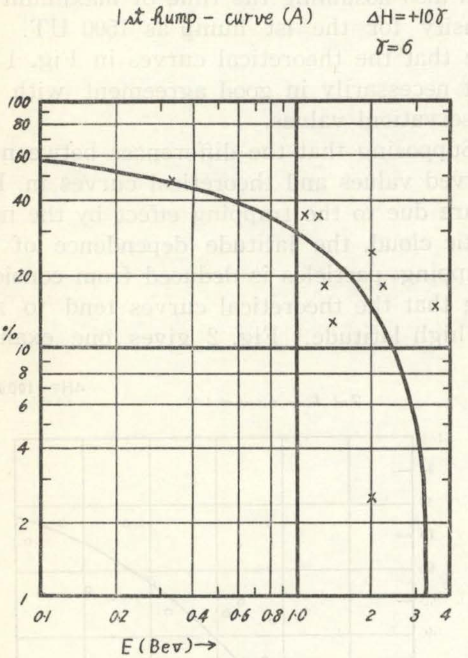


Fig. 3. One example of the energy spectra of cosmic ray particles trapped by the solar magnetic cloud in case of the 1st hump.

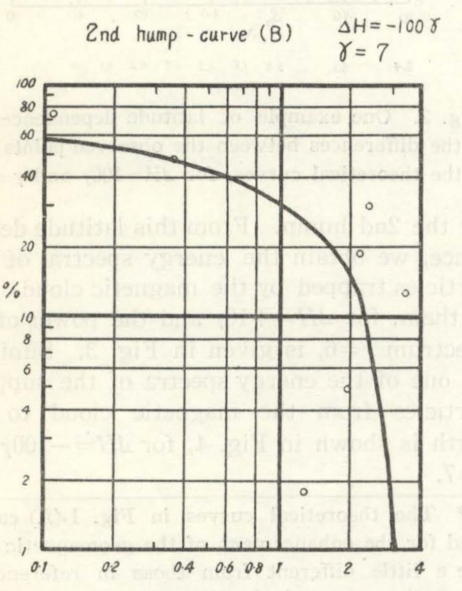


Fig. 4. One example of the energy spectra of cosmic ray particles supplied by the solar magnetic cloud in case of the 2nd hump.

## § 3. The Propagation Process of the Solar Cosmic Rays in the Interplanetary Space on November 15, 1960

Fig. 5 shows the increases of the cosmic rays on November 15, at Syowa Base (69.0°S geomagnetic latitude) and Churchill (68.7°N). It is clearly seen from the figure that the onset time at Syowa Bases is about one hour earlier than that of Churchill, as well as the difference in the rise time between both stations. Using the observed data from seven stations* belonging to the Arctic or the Antarctic region, the dispersions in the rise time of the November events among seven stations are given in Fig. 6, showing that the dispersion of the November 15 event is much larger than those of the other two events. From these observed facts, the di-

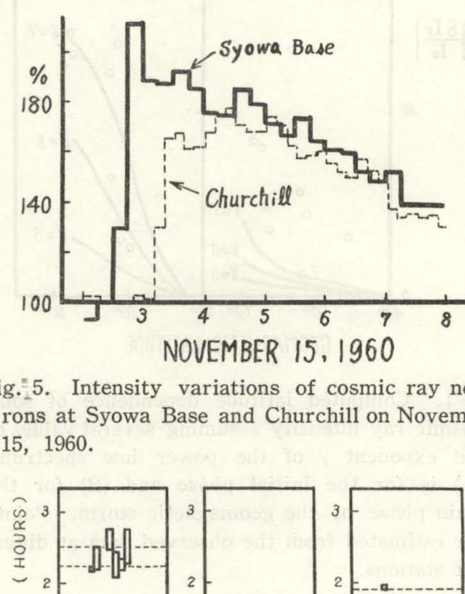


Fig. 5. Intensity variations of cosmic ray neutrons at Syowa Base and Churchill on November 15, 1960.

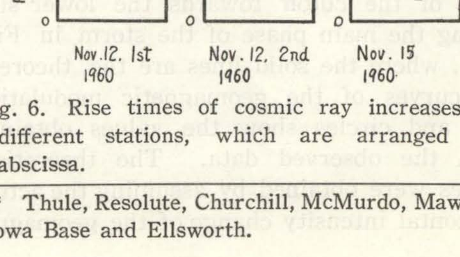


Fig. 6. Rise times of cosmic ray increases at different stations, which are arranged on abscissa.

* Thule, Resolute, Churchill, McMurdo, Mawson, Syowa Base and Ellsworth.

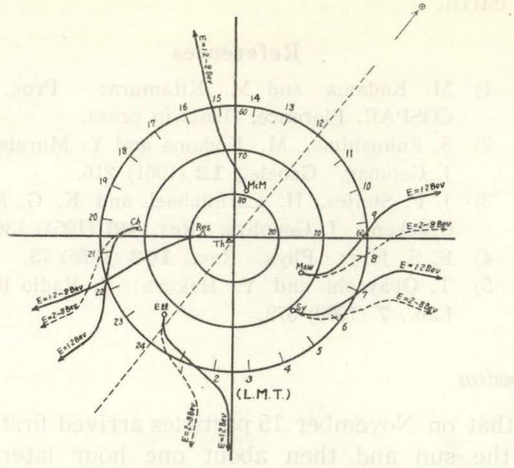


Fig. 7. Asymptotic orbits in the equatorial plane of the cosmic rays entered to the respective stations.

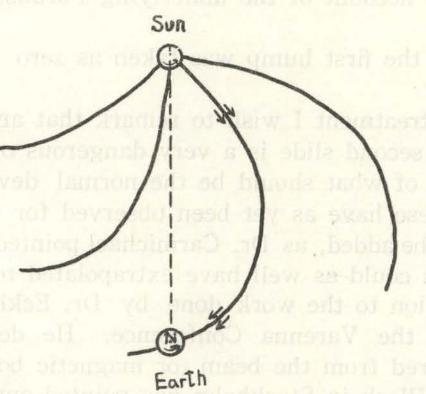


Fig. 8. The curved solar magnetic field along which solar cosmic ray particles propagate to the earth.

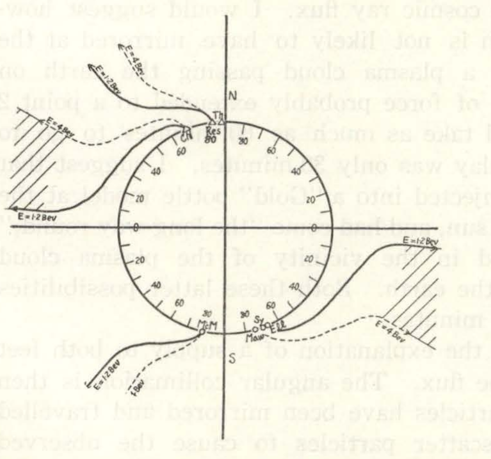


Fig. 9. Asymptotic orbits in the meridian plane of the cosmic rays entered to the respective stations.

rection of the anisotropy of the solar cosmic rays in the interplanetary space and their propagation process are examined by taking account of the asymptotic orbits.

The asymptotic orbits[4] in the equatorial plane are shown in Fig. 7. From this figure, in connection with the fact that the early enhancement was observed at Mawson, Syowa Base, Ellsworth and about one hour later at Churchill, it is suggested that first the main flux of the solar cosmic ray particles came to the earth from the morning side and next about one hour later came from the afternoon side. Thus, the propagation of the solar cosmic ray particles along the curved solar magnetic line of force[5] in the equatorial plane are imagined as shown in Fig. 8.

Next, the asymptotic orbits in the meridian plane are shown in Fig. 9. This figure leads, together with the fact of the different rise time in the different localities, is to the conclusion that first of all the main part of the solar cosmic ray particles came to the earth from the direction of the geomagnetic latitude 5°—30° south and successively about one hour later came from the opposite direction of 5°—30° north. And it is suggested that the solar cosmic ray particles from the other directions came to the earth by the drift or diffusion process, resulting in the gradual enhancement of the intensity.

As a possibility, the propagation process of the solar cosmic ray particles in the interplanetary space during the Forbush decrease is imagined as shown in Fig. 10. In brief, first the main flux of the solar cosmic ray particles come to the earth from the direction of 5°—30° south along the magnetic line of force in the cloud responsible for the

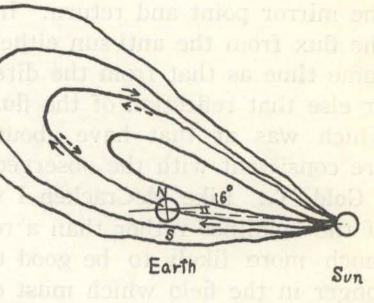


Fig. 10. The schematic model of the solar magnetic cloud which affected on solar and galactic cosmic rays.

Forbush decrease to produce the early sudden enhancement at Mawson, Syowa Base, Ellsworth, and next they reflect at the mirror point in this magnetic cloud and come back to the earth from the direction of 5°—30° north to produce the later enhancement at Churchill. And particles which propagate along the other magnetic lines of force come to the earth by the drift or diffusion process, resulting in the gradual enhancement of the cosmic ray intensity at other stations on the earth.

### References


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### *Discussion*

**Carmichael, H.:** (1) The demonstration that on November 15 particles arrived first at the earth from the general direction of the sun and then about one hour later from the opposite direction is a most important contribution because of the possible interpretation in terms of the Gold model.

(2) May I ask, with regard to the derivation of the spectrum at the time of the second hump on November 12, did you take account of the underlying Forbush decrease?

**Kitamura, M.:** Yes, mean intensity before the first hump was taken as zero level intensity of the 2nd hump.

**Sandström, A. E.:** From the point of data treatment I wish to remark that an extrapolation such as you have shown in your second slide is a very dangerous operation to perform. It necessitates a knowledge of what should be the normal development of a solar flare effect. Too few of these have as yet been observed for us to speak of a normal appearance. To this is to be added, as Dr. Carmichael pointed out, the F.d. which has to be accounted for. You could as well have extrapolated to one single flare effect. I wish to draw the attention to the work done by Dr. Eckhandt on the February 23, 1956 event, presented at the Varenna Conference. He demonstrated the possibility of particles being scattered from the beam (or magnetic bottle). He assumed a scattering process. Later Dr. Block in Stockholm has pointed out that at the boundary of a beam (magnetic bottle) the line of force favour the escape of particles.

**McCracken, K. G.:** My analysis of the November 15 event is in complete agreement with your analysis at the anisotropies in the cosmic ray flux. I would suggest however that the flux from the anti-sun direction is not likely to have mirrored at the sun, for the magnetic require was set up by a plasma cloud passing the earth on November 13. By November 15, the lines of force probably extended to a point 2 AU past the earth, and hence the flux would take as much as 60 minutes to go to the mirror point and return. In fact, the delay was only 30 minutes. I suggest that the flux from the anti-sun either had been injected into a "Gold" bottle model at the same time as that from the direction of the sun, and had come "the long way round," or else that reflection of the flux had occured in the vicinity of the plasma cloud which was at that have about 2 AU past the earth. Both these latter possibilities are consistent with the observed delay of 30 minutes.

**Gold, T.:** Like McCracken I would favour the explanation of a supply to both feet of the fieldlines rather than a reflexion of the flux. The angular collimation is then much more likely to be good than when particles have been mirrored and travelled longer in the field which must confuciously scatter particles to cause the observed isotropy.