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II-4-6. Mechanism of Cosmic Ray Storms Inferred from Some Statistical Results*

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Recently, evidence that cosmic ray storms (Forbush decreases) are usually corresponding to solar flare accompanying with major solar radio outbursts on VHF band, so called Type IV outbursts, has been reported by Japanese investigators. In the present investigation, above evidence is confirmed fairly well by extended data of four years including IGY, besides, some statistical results on cosmic ray storms concerning with heliographic position of flares and propagation time of storms are found.

It is concluded that the larger cosmic ray decreases are apt to excited by the geomagnetic disturbances having the shorter propagation time and the flares locating at nearly 30 degrees east heliographic longitude. These facts leads to the conception that an expanding corpuscular cloud having intense magnetic field in the front filled with cosmic rays trails towards the east, so that cosmic ray storms are the biggest by flare of solar east hemisphere.

Discussion is also presented on physical picture of the cloud concerning to cosmic ray storms.

Introduction

Evidence that cosmic ray storms are almost corresponding to solar flare with major radio outbursts on about 200 Mc, so called Type IV outbursts has been investigated[1]. This correspondence is confirmed fairy well by extended data of four years including IGY period, from January, 1956 to December, 1960, that is, 50 cases out of 61 cases of Type IV solar radio outbursts corresponding to cosmic ray storms which decrease more than 0.5% from undisturbed level.

It is plausible to consider that the corpuscular cloud responsible to cosmic ray storms have intense magnetic field, since Type IV outbursts are considered as the evidence of synchrotron radiation from relativistic electrons under strong magnetic field.

Used data in the present investigations are neutron observations at Mt. Norikura, Japan and at Deep River, Canada, which are corrected from change of cut off rigidity depend to the geomagnetic disturbances, *Ist*, by means of horizontal field component observed at Kakioka Magnetic Observatory, Japan[2].

Then, corrected value, ΔI^*, is given by the relation

$$\Delta I^* = \Delta I - Ist, \qquad (1)$$

here, ΔI is deviation from undisturbed level of cosmic ray intensity.

Statistical Investigations

a. Propagation Time

Relation between cosmic ray decreases during storms and propagation times, ΔT (time from the outbursts to beginning of the concurrent geomagnetic storms.) are shown in Fig. 1 (a) and (b), Norikura and Deep River, respectively.

It is easily concluded from this figures that the bigger cosmic ray storms are apt to excited by the higher speed cloud, though, the converse do not hold good. The same tendency is also true on geomagnetic storms, however, correlation is more close on cosmic ray storms than geomagnetic storms.

Though, we have no concern with any measures on generating abilities of cosmic ray storms, G, cosmic ray decreases might be given the relation

$$\Delta I^* \propto G \cdot \frac{1}{\Delta T} \propto G \cdot V, \qquad (2)$$

here, V is mean propagation velocity of the

* This paper was combind with (II-4-5) (II-4-7) and (II-4-8), and presented by I. Kondo in II-4-31.

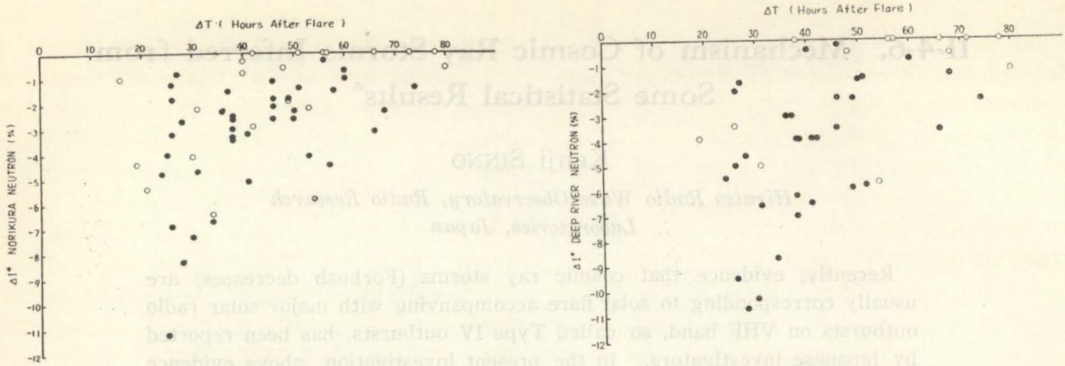

Fig. 1. (a) Fig. 1. (b)

Fig. 1. (a), (b) Cosmic ray Forbush decreases *vs* the propagation times (hours from flare to onset of magnetic storm). (a) is Mt. Norikura and (b) is Deep River, and black dots representing more significant cases than white dots.

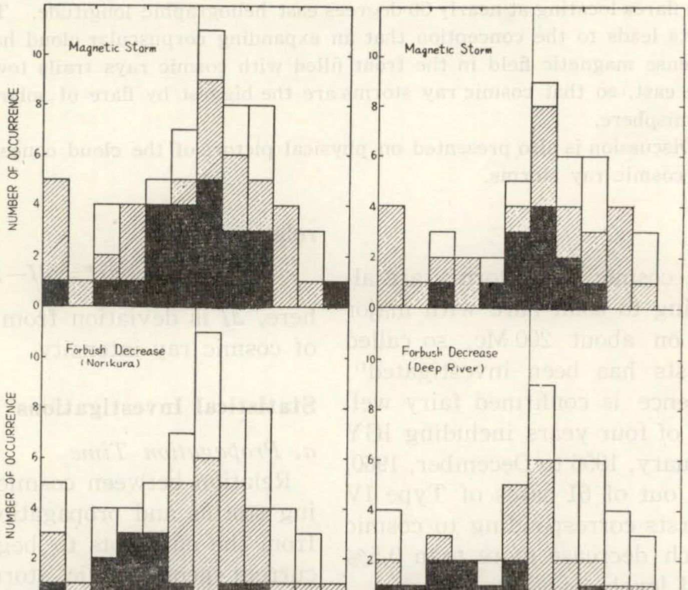

Fig. 2. (a), (b) Magnitude of magnetic storms and cosmic ray storms *vs* heliographic longitudes. (a) Mt. Norikura, (b) Deep River. Dividing activities of magnetic storms into three ranks, less 5_+, $6_- \sim 7_+$ and over 8_- in Kp, expressing by blank, shade and black, respectively. And, dividing decreases of cosmic ray intensities into three ranks, $-\Delta I^* < 2\%$, $2\% \leqq -\Delta I^* < 4\%$ and $-\Delta I^* \geqq 4\%$ at Mt. Norikura, and $-\Delta I^* < 3\%$, $3\% \leqq -\Delta I^* < 6\%$ and $-\Delta I^* \geqq 6\%$ at Deep River, expressing by blank, shade and black, respectively.

corpuscular cloud.

b. Solar Longitude

Next, we must examine the characteristics of cosmic ray storms on the flare position. This tendency expresses plainly in bottom figures of Fig. 2 (a) and (b), Mt. Norikura and Deep River, respectively, that is, the large cosmic ray decreases are excited by the flare located about 30 degrees east, on the other hand, the large magnetic storms are excited by central flares, as shown in upper figures of Fig. 2 (a) and (b).

Therefore, the cosmic ray storms may be given by

$$\Delta I^* \propto \frac{G \cdot F(\lambda)}{\Delta T} = G \cdot V \cdot F(\lambda)\,, \tag{3}$$

here, $F(\lambda)$ is the longitudinal function of cosmic ray storms.

Besides, we can find a definit tendency on the durations of cosmic ray storms instead of decreases, as shown in Fig. 3. Here, we show the tendency deriving from only Deep River, because estimation of the durations from Norikura are too ambiguous for small decreasing during the storm.

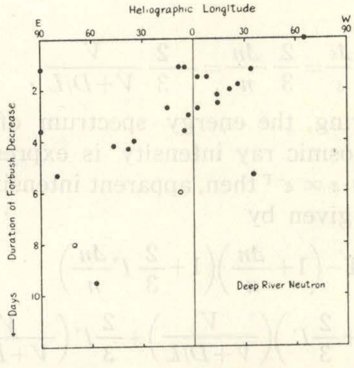

Fig. 3. Durations of cosmic ray Forbush decreases *vs* heliographic longitudes.

Configuration of Cosmic Ray Storms

We have had an observational fact by the space probe Pioneer *V*, that is, cosmic ray storm is not only local phenomenon around the earth environment, but prevails fundamentally in the interplanetary space nothing to do with earth. Thus, we could safely displace time variation of the cosmic ray storms into spatial intensity distribution in the interplanetary space. Spatial intensity distributions of averaged cosmic ray storm derived from both decrease and durations of cosmic ray storm is given, as shown in Fig. 4. Cosmic ray storm in the interplanetary space is like a twisted and expanding balloon towards the east and it's foot is linked to the flare region which is rotating to west with solar rotation. And, angle of ejection is quite broad so that cosmic ray storm is excited by the flare in visible solar surface, except in west most region.

Similar shape of the cloud has been represented by J. H. Piddington[3] from theoretical point of views and also supposed by J. S. Steljes, H. Carmichael and K.G. McCracken[4] from observational points of views on unusual increases of cosmic ray.

Proposed Model on Cosmic Ray Storms and Solar Soft Cosmic Ray Increases

The twisted shape of cosmic ray distribution in the interplanetary space as shown in Fig. 4, brings back to the speculative corpuscular stream emitting from *M*-region, where the particles emit successively much like water from a rotating garden hose. However, corpuscular cloud ejected from the flare would not take such form, since duration of corpuscle emission from the flare is only short time.

On the other hand, the corpuscular cloud responsible to geomagnetic disturbances advances straightly in interplanetary space, so that the generating flares distribute around solar central meridian. Suppose that the corpuscular cloud which contains strong mag-

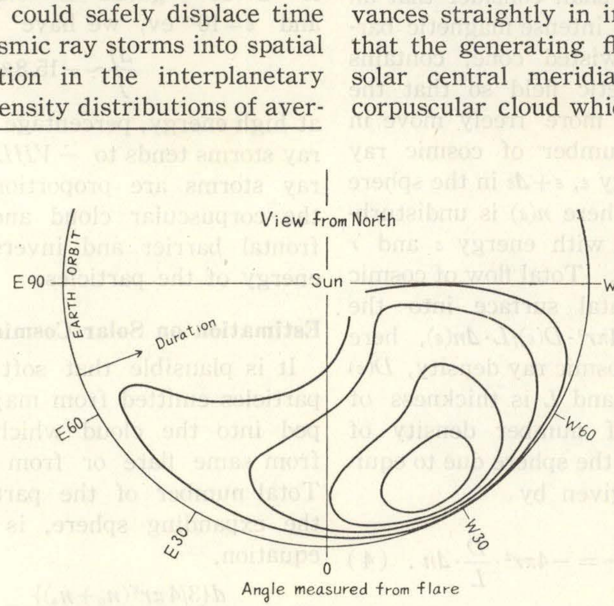

Fig. 4. Schematical representation on distribution of cosmic ray intensities in interplanetary space.

netic field, advances straightly into the interplanetary space, and the trailing field behind the cloud is linking to the flare region fixed on the rotating sun. Then, we could get the shape of the cloud we are seeking. Here, we may say that the word of "cloud" have two faces, the field is responsible to the cosmic ray storms and the particle is responsible to the geomagnetic storms.

Next, we would like to point out some of observations by space probe Pioneer V launched March 11, 1960[5]. Any hypotheses on the cosmic ray storms should not contradict with the observations of Pioneer V. The observations insist that the front of the cloud is consisted by rather intense magnetic field with either smooth or irregular, though the behind of the cloud is filled by weak and irregular or smooth and radial magnetic field.

We shall discuss the cosmic ray storms and the soft solar cosmic ray increases in the following model, that is, the expanding magnetic field in the front of the cloud prevents incoming cosmic ray as well as outgoing cosmic ray, and deceleration is took place to the cosmic ray in the cloud by means of inverse Fermi mechanism which acts proportional to the velocity of the cloud.

Estimation on Cosmic Ray Storms

For simplicity, we shall consider that an expanding sphere with intense magnetic barrier instead of the twisted cone, contains weak or radial magnetic field so that the energetic particles can more freely move in the interior. Total number of cosmic ray particles with in energy ε, $\varepsilon+\Delta\varepsilon$ in the sphere is given by $4/3\pi r^3 n(\varepsilon)$, here $n(\varepsilon)$ is undisturbed cosmic ray density with energy ε and r is radius of the sphere. Total flow of cosmic ray through the frontal surface into the sphere is given by $-4\pi r^2\cdot D(\varepsilon)/L\cdot\Delta n(\varepsilon)$, here $\Delta n(\varepsilon)$ is increment of cosmic ray density, $D(\varepsilon)$ is diffusion coefficient and L is thickness of the front. Change of number density of cosmic ray particles in the sphere due to equithermal expansion is given by

$$\frac{d\{4/3\cdot\pi r^3(n+\Delta n)\}}{dt}=-4\pi r^2\cdot\frac{D}{L}\cdot\Delta n\,. \quad (4)$$

Neglecting $\frac{d\Delta n}{dt}$, we get

$$\frac{\Delta n}{n}=-\frac{V}{V+D/L}\,, \quad (5)$$

here, V is velocity of frontal surface.

On the present case, if the particle velocities are randomized by collisions during the expansion, then $\varepsilon\propto n^{2/3}$ is held[6]. If kinetic energy transfer prevails through the front as the same way for diffusion process, the energy deviation is given by the same equation[4].

Thus,

$$\frac{\Delta\varepsilon}{\varepsilon}=\frac{2}{3}\frac{\Delta n}{n}=-\frac{2}{3}\frac{V}{V+D/L}\,. \quad (6)$$

Considering, the energy spectrum of undisturbed cosmic ray intensity is expressed by $j(\varepsilon)=n(\varepsilon)\cdot\varepsilon\propto\varepsilon^{-\Gamma}$ then, apparent intensity deviation is given by

$$\frac{\Delta j(\varepsilon)}{j}\sim 1-\left(1+\frac{\Delta n}{n}\right)\left(1+\frac{2}{3}\Gamma\frac{\Delta n}{n}\right)$$
$$=-\left(1+\frac{2}{3}\Gamma\right)\left(\frac{V}{V+D/L}\right)+\frac{2}{3}\Gamma\left(\frac{V}{V+D/L}\right)^2. \quad (6)$$

The diffusion coefficient is given by $D=1/3\,lv$, where l is transport mean free path and v is particle velocity. We assume l as equal to the spiral radius of a protons with energy ε (in ev unit) in magnetic field H, then, l equals Larmor radius, $l=\varepsilon/300H$. For $\Gamma=1.5$, $V=10^8$ cm/sec, $v=3\times10^{10}$ cm/sec, $H=2\times10^{-4}$ gauss $L=0.1$ A.U $=1.5\times10^{12}$ cm and $\varepsilon=10^{10}$ ev, we have

$$\frac{\Delta j}{j}\sim-15.8\%\,,$$

at high energy, percentage decrease of cosmic ray storms tends to $-VHL/\varepsilon$, that is, cosmic ray storms are proportional to velocity of the corpuscular cloud and strength of the frontal barrier and inverse proportional to energy of the particles.

Estimation on Solar Cosmic Ray Increases

It is plausible that soft solar cosmic ray particles emitted from major flare are trapped into the cloud which is ejected either from same flare or from forerunning flare. Total number of the particles injected into the expanding sphere, is controlled by the equation,

$$\frac{d\{3/4\pi r^3(n_0+n_s)\}}{dt}=-4\pi r^2\frac{D}{L}n_s\,, \quad (8)$$

here, n_s is number density of solar cosmic ray particles and n_0 is number density of undisturbed cosmic ray particles.

Then, apparent solar cosmic ray intensity is given by

$$j_s = j_{s0}\left\{\left(1+\frac{2}{3}\Gamma'\right)t^{-3(1+k)} - \frac{2}{3}\Gamma' t^{-6(1+k)}\right\} \quad (9)$$

$$k(\varepsilon) = \frac{t}{r}\cdot\frac{D(\varepsilon)}{L} \quad (10)$$

here, energy spectrum of solar cosmic ray intensity is expressed by $j_s(\varepsilon) \propto \varepsilon^{-\Gamma'}$ and Γ' is $2\sim4$ times larger than that of undisturbed cosmic ray intensity.

Here, $k(\varepsilon) \ll 1$ is safely held in energy ranges of under Bev in protons, ($k\sim1$ at $\varepsilon\sim1$ Bev), so we can easily see the solar cosmic ray increase tends to t^{-3} after comparatively long time from particles injection. (Here, if the expansion of the cloud is two dimensional, the power takes -2 instead of -3). Decay of the soft solar cosmic ray observed by counter of balloon[7] and radio absorptions[8] may support the result of this estimation.

However, in the more high energy ranges, above simple estimation may fails to agree with observations. Because, the particles trapping into the cloud become not so effective that the particles escape to outer region and is trapped again by another barrier located beyond the earth, which has been proposed by several investigators.

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