$$L\bar{n} \gg \frac{2\pi c^2}{e^2} \frac{m_0 R}{(1-\beta^2)^{\frac{1}{2}}} .$$

Since $L \sim 10\, R$, this calls for

$$\bar{n} \gg \frac{2\pi c^2 m_0}{10 e^2 (1-\beta^2)^{\frac{1}{2}}} . \qquad (17)$$

Now

$$\bar{n} = 2\pi^2 R_0 a_0^2 n_0 .$$

Hence, (17) becomes

$$\pi R_0 a_0^2 n_0 \gg \frac{m_0 c^2}{10 e^2 (1-\beta^2)^{\frac{1}{2}}} .$$

Putting $R_0 = 10^9$, $a_0 = 10^8$, $n_0 = 1000$, this gives

$$0.6 \times 10^{28} \gg \frac{6 \times 6 \times 10^{-24} \times 10^{21}}{10 \times 25 \times 10^{-20} (1-\beta^2)^{\frac{1}{2}}}$$

or

$$10^{28} \gg \frac{20 \times 10^{15}}{(1-\beta^2)^{\frac{1}{2}}} .$$

In other words, not until $(1-\beta^2)^{-\frac{1}{2}}$ became of the order 10^{12}, and the energy became 10^{12} times the rest energy, would the first term on the left hand side of (16) become important. Thus (16) may, for practical purposes,

$$\frac{LI}{c} = N_0 - N$$

which is the form we have used in our previous discussion, leading to

$$\frac{LI}{c} = N_0$$

when the ring has proceed out of the primary field.

JOURNAL OF THE PHYSICAL SOCIETY OF JAPAN Vol. 17, SUPPLEMENT A-III, 1962
INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part III

III-3-10. On the Origin of Cosmic Rays*

Satio HAYAKAWA

Physical Institute, Nagoya University, Nagoya, Japan

Among divergent opinions on the origin of cosmic rays, one could perhaps find agreement in the following points. Two of them have already been noticed by Fermi in his epoch making theory and the third one has been emphasized by Hoyle, Ginzburg, Shklovskij and Oort, based on a number of evidences.

(I) Magnetic storage of cosmic ray particles in the Galaxy.

(II) Slow acceleration of particles by varying magnetic fields.

(III) Supernova origin as one of the most powerful sources.

If one wishes to go farther in each of the above points, there arise a number of different views which would not always make everybody happy. They may be listed up as follows.

(I-1) The stored region extends to the Galactic halo and particles in the halo and the Galactic plane are well mixed[1]. This may be accepted by the majority, but a small fraction of cosmic rays we are observing may not be in equilibrium but could be affected by near-by sources, as will be discussed later[2].

(I-2) The mean lifetime of stored cosmic rays is determined mainly by the escape from the Galaxy, but not by the nuclear absorption[3]. This is in essential agreement with the observed abundances of the light group and electrons which are regarded as the products of nuclear interactions with the interstellar matter whose thickness traversed by cosmic rays is estimated to be rather small[3),4)]. However, there seem to be at least two experimental results which could be regarded as evidences against the above view. One is the isotopic ratio of helium

* This review is prepared for introducing the papers presented in the ordinary session of "Origin" and for giving a general picture on the origin of cosmic rays.

nuclei[5] and the other the spectrum of general Galactic radio emission[1),6)]. The observation of Galactic photons should give us decisive information on this question[7)].

(II-1) The acceleration takes place mainly in active sources[8)]; the interstellar space in general in the arms as well as in the halo seems to be rather ineffective, because the energy responsible for the acceleration does not seem to be sufficient in the interstellar space on one hand and the presence of high energy heavy nuclei[9)], if the experimental results reported by some authors are approved, contradicts the statistical interstellar acceleration on the other hand.

(II-2) The acceleration at active sources may be of statistical one, no matter whether it is due to the longitudinal (Fermi) or the transverse (Swann) compression of magnetic fields, which may also be responsible for the first order, non-statistical acceleration[1),10)]. It seems to be worthwhile to remark Syrovatsky's suggestion[11)] that the $E^{-3/2}$ spectrum comes out of the equipartition of energy among three modes, turbulent motions, magnetic fields and cosmic rays.*

(III-1) Supernovae, possibly novae too, are responsible for the major part of Galactic cosmic rays. A question whether the supernova explosion fits this idea or not was examined by detailed investigations of the explosion mechanism[14),15)].

(III-2) Cosmic ray sources are rich in heavy nuclei in comparison with the average relative abundances in the Galaxy. This may be attributed either to the enrichment of heavy elements in the supernova envelope[16)] or to the preferred acceleration of heavy nuclei[10)].

There exist active galaxies which are producing cosmic rays with very high efficiency. However. their contribution to observed cosmic rays is rather doubtful[1)], except for particles of the highest energies.**

In connection with the above views, let us introduce some essential points of papers discussed in the ordinary sessions together with new information on the primary cosmic radiation.

(A-1) *Isotopic abundance of* He *in primary cosmic rays.*

The Rochester group[5)] obtained a high relative abundance of ^{3}He (about 25%) among primary helium nuclei. This cannot be interpreted in terms of the fragmentation of heavier nuclei due to their collisions with matter in the interstellar space as well as near their sources[1),3)]. Two possible interpretations have been presented; (i) at sources heavy nuclei such as iron are mainly accelerated, so that the fragmentation alone results in the nearly equal abundances of ^{3}He and ^{4}He, or (ii) the cosmic abundances thus far adopted may be revised by reference to the recent discovery of helium stars. Postponing the discussion of (i) later in (D), here we mention a paper by Burbidge and Burbidge[18)] concerning (ii).

Although there exist several pieces of information which may increase the value of ^{3}He/^{4}He in the cosmic abundances, they pointed out difficulties in finding out a reasonable mechanism of the ^{3}He production even at ^{3}He rich stars. The most likely process seems to be the thermonuclear synthesis due to the $p-p$ chain, in which the temperature is so low that ^{3}He can be pro-

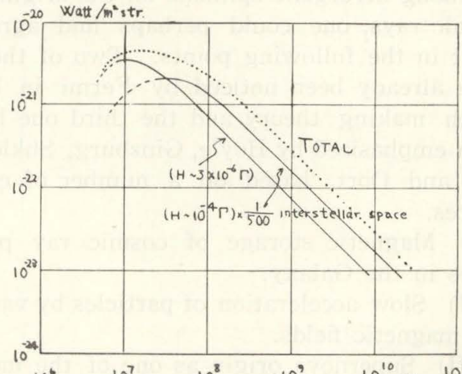

Fig. 1. Differential momentum spectra of primary electrons and positrons.

P: Assumed differential momentum spectrum of protons in the interstellar space.

e: Differential momentum spectrum of electrons ($e^- + e^+$) calculated from P.

e^+, e^-: Differential momentum spectra of positrons and electrons respectively.

Experimental results[20)] are shown by crosses.

---

* In the plenary session of "Origin" two interesting theories were suggested respectively by Swann[12)] and by Alfvén[13)].

** A number of attractive ideas on the metagalactic origins are discussed by Burbidge[17)] on the basis of recent astronomical evidences.

duced but the $^3He+^3He$ reaction hardly occurs. Whether such a mechanism is acceptable or not depends on the formation and the evolution of stars. Before going farther into serious considerations on this problem, it seems worth while to remark that the cosmic ray evidence should not be considered as decisive. In fact, another experiment[19] shows the relative abundance of ^3He as low as 8±8%.

(A-2) *Electrons and Galactic radio emission.*

The Galactic radio emission provides information on relativistic electrons, particularly on their spatial and energy distributions. The strong radio intensity in a disk containing the Galactic plane may be attributed to the high magnetic field strength therein, although the spatial distribution of electrons may also affect it to some extent. The relativistic electrons are regarded as due to the collisions of cosmic rays with the interstellar matter. Recent observations on primary electrons[20] seem to be in fair agreement with the secondary electron hypothesis, as shown in Fig. 1[21]. For future use the energy spectra of electrons and positrons are separately shown.

However, the radio spectrum thus expected seems to be steeper than the observed one[1),6)]. Nevertheless, the less steep spectrum around 100 Mc/s is shown to be due to the flattening of the spectrum of pions produced by nuclear collisions, as shown in Fig. 2. Therefore, the experimental results on the electron intensity as well as the radio spectrum does not seem to be inconsistent with the assumption that the electrons are mainly produced by the nuclear collisions.

In deriving the radio spectrum one has to be cautious about the spatial fluctuations of magnetic fields and electron intensities, as emphasized in reference 1. Hence one will have to examine the possibility that the average energy of electrons depend on the magnetic field strength which fluctuates from place to place. If electrons are magnetically trapped in a spatial region during a considerable time interval which is, however, shorter than their average lifetime, those trapped in a strong magnetic field lose energy more quickly than those in a weak field. The radio frequencies from these two sources correspond to different energies of electrons therein, lower in the former and higher in the latter. Hence the radio spectrum due to their superposition is flatter than that expected from the average energy spectrum of electrons in the average magnetic field. This feature is illustrated in Fig. 2. That is to say, the average processes employed for obtaining the radio spectrum are not commutative. The above suggestion will be examined by observing the spatial dependence of the radio spectrum.

(B) *Heavy nuclei at high energies.*

Now we turn our attention to a high energy region. A number of authors, especially Peters, have emphasized that the largest extensive air showers may be initiated mainly by heavy nuclei. If the relative abundances of heavy primaries observed at low energies continue to hold at extremely high energies, the relative contributions of protons, He, M, H and VH groups to the EAS of given size are estimated to be nearly equal.

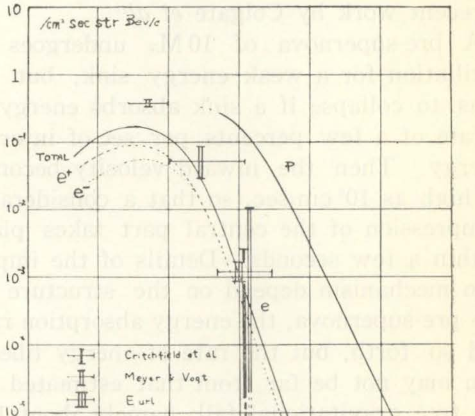

Fig. 2. Galactic radio spectrum expected from the secondary electrons, whose energy spectrum is given in Fig. 1.

The radio spectra are obtained for two extreme values of the magnetic field strength, one $H=3\times10^{-6}$ gauss and the other $H=10^{-4}$ gauss, the latter occupying 1/500 of the Galactic volume. The dotted curve represents the sum of these two contributions. The power index of this spectrum, $\nu^{-\gamma}$, is evaluated as

$\gamma \simeq 0.3$ for 20 Mc/s $\leq \nu \leq$ 50 Mc/s.

$\gamma \simeq 0.9$ for 200 Mc/s $\lesssim \nu \lesssim$ 300 Mc/s.

If there exists a cut-off in the rigidity spectrum, the EAS of sizes greater than a certain value may be produced exclusively by heavy nuclei. An EAS initiated by a heavy nucleus is characterized by the richness of μ-mesons[9]. Although the definite identification of a heavy initiated EAS is not yet possible, this will become one of the central problems of cosmic ray physics in the next years.

(C-1) *Supernova explosion*[14),15]

Among various sources of cosmic rays it is doubtless that the supernova is one of the most powerful candidates. The supernova is believed to be the latest stage of evolution of a star with mass beyond a certain limit, so that the nuclear energy in its central part has been almost consumed. The gravitational energy left thereafter can give rise to the implosion when the degree of freedom of motion decreases. Although no theory is conclusive yet, the implosion mechanism may be illustrated by reference to a recent work by Colgate *et al*[15].

A pre-supernova of 10 $M_{\odot}$ undergoes an oscillation for a weak energy sink, but begins to collapse if a sink absorbs energy at a rate of a few percents per sec of internal energy. Then the inward velocity becomes as high as 10^8 cm/sec, so that a considerable compression of the central part takes place within a few seconds. Details of the implosion mechanism depend on the structure of the pre-supernova, the energy absorption rate and so forth, but the rate of energy liberation may not be far from that estimated as the free gravitational fall; namely about 10^{52} ergs are liberated within seconds. This can trigger a shock that results in the supernova explosion.

The shock wave thus generated propagates outward. As the density decreases with increasing radius, the shock strength increases with radius, compensating its decrease by the spherical damping[14]. Behind the shock front follows a gas flow whose velocity also increases with radius until it reaches the escape velocity. Since the escape velocity is reached at about a half radius, the mass thrown out may be about one tenth of the stellar mass. Since the thrown out part has been swept by the shock wave, the temperature therein has been as high as 10^9°K, so that rapid nuclear reactions must have taken place. The rapid nuclear reactions may be responsible not only for the enrichment of heavy elements, but also for the anomaly in cosmic ray abundances, such as the overabundance of carbon compared with oxygen[16].

Details of the explosion mechanism are still under investigation and the above picture should be taken with reservation. In fact, two independent works[14),15] give results considerably different from each other. Those which are agreeable with each other are results based on the conservation of energy in the non-relativistic region. However, the initial energy inputs are different in respective works and so are the time intervals during which an enormous amount of energy, say 10^{52} ergs, is liberated. Moreover, another difference in relation to energetics lies in the spherical[14] and one-dimensional[15] modes of shock propagation. It seems, therefore, too early to expect quantitative information on the origion of cosmic rays from this kind of theory.

The same reservation seems to be kept in mind concerning an interesting suggestion on the acceleration by an electric field caused by the charge separation at the shock front[15]. It has been pointed out that the high electric field responsible for the acceleration may give rise to a photon gas of high temperature, so that heavy nuclei may be destroyed by photo-disintegrations[1].

(C-2) *Equipartition of energy into three modes.*

As stated in (II), the major cause of acceleration cannot be attributed to the mechanism as above, but to slow processes of statistical nature. The energy spectrum of cosmic rays expected from the statistical acceleration depends on the rate of energy gain and rate of particle loss from an accelerating region. These quantities should vary from one accelerating region to another, so that one would expect a variety of energy spectra depending on sources. However, the spectra at different sources appear to be alike on account of the radio spectra as well as the cosmic ray spectrum; their integral energy spectra of relativistic particles are approximately represented as $E^{-3/2}$. This is shown to be accounted for in terms of the hypothesis that the total energy is equally distributed among three modes, the turbulent motion, the magnetic field and the cosmic rays[1),11)]. This suggestion is of great interest in connection with the energy partition among various modes in cosmic plasmas.

(C-3) *Preferential acceleration of heavy nuclei*[1),10)].

The relative abundances of heavy nuclei in cosmic rays are found to be richer than the cosmic abundances, as nuclei become heavier. The latter of two possible explanations of this fact, mentioned in (III-2), based on the higher rate of energy gain of heavier ions. The rate of energy gain in the statistical acceleration is proportional to the mass of a particle accelerated, if the charge is the same, and may increase with the mass, even if the ionization process in its course of acceleration is taken into account. It may, therefore, be the case that the rate of energy gain is greater than the rate of energy loss only for the heaviest nuclei such as iron. A crucial test of this possibility will be provided with observing the charge spectrum of solar particles. Concerning the Galactic cosmic rays, however, the low abundance of nuclei of $Z=15\sim19$ seems to be not in favour of this acceleration mechanism, although the conclusion should be reserved until a more careful analysis of fragmentation processes is made.

(D) *Range of metagalactic cosmic rays.*

The probable existence of magnetic fields in the intergalactic space prevents cosmic ray particles from propagating in a straight way. Therefore, only those particles that are originated within 10^8 l.y. can arrive in our Galaxy within the cosmic age. The situation does not change even in the steady state cosmology, because the recession velocity increasing with distance results in the same range of metagalactic cosmic rays[1)].

An additional effect arises for the heavy nuclei of high energies[22)]. Their collisions with intergalactic photons lead to photodisintegrations; since the photoreaction has a sharp resonance at laboratory photon energies around 20 MeV, this effect is enhanced for the energy per nucleon of around 10^{17} eV. However, the photoreaction does not completely destroy a nucleus, so that a number of collisions are needed for eliminating heavy nuclei.

The effect of the intergalactic photons also limits the range of metagalactic photons of energies above 10^{12} eV due to the pair creation process[22)]. The ranges of the heavy nuclei and the photons are thus limited to about 10^8 l.y. in both cases.

(*E*) *Relation to the Galactic structure.*

The astrophysical significance of cosmic rays have been regarded mainly as a carrier of information of celestial objects. In addition to this passive role, it is now recognized that cosmic rays play an active role in the structure and the evolution of the galaxy in the following respects.

(E-1) *Anisotropy of high energy heavy primaries.*

A probable indication of the anisotropy has been found for extensive air showers containing relatively many μ-mesons[9)]. They may be attributed to heavy nuclei of energies per nucleus of about 10^{17} eV or greater. This may be interpreted as due to the preferential contribution of near-by sources[2)]. Cosmic rays from such a source are of relatively short age, so that they are neither well stirred by magnetic fields nor suffer from nuclear collisions with the interstellar matter even for the heaviest nuclei. Hence these cosmic rays may not be isotropic and contain relatively more heavy nuclei. Although the intensity of these protons is smaller than that of general, isotropic cosmic ray protons, the amount of heavy nuclei from this source may be comparable to that of isotropic ones. If the source is located in a magnetic bottle, in which also the earth lies, particles with small pitch angles escape faster, and the relative population of particles with large pitch angles increases with time. Thus one may observe particles preferentially perpendicular to the magnetic line of force. If the magnetic bottle lies along the Galactic arm, the above explanation is consistent with the observed anisotropy.

(E-2) *High density of cosmic rays in particular regions.*

The above theory may lead to the possibility that the intensity of cosmic rays is higher than the average value in the vicinity of the source. If this is the case, the cosmic ray pressure makes the magnetic bottle expand until it becomes as low as the magnetic pressure. The anisotropy discussed in (E-1) seems to correspond to the equilibrium case. In an earlier stage, however, one would expect a high intensity region, in which magnetic fields are considerably distorted. In fact, such a region seems to be seen from the anomalously high intensity of radio emission from a region along a Galactic arm[23]. The distortion of the magnetic field from the rather regular arm field is indicated by the polarization of star light coming through this region.

This observation together with the interpretation of the anisotropy in (E-1) can be incorporated with the supernova origin hypothesis. The energy density of cosmic rays as well as relativistic electrons from a supernova is far greater than the magnetic energy density in the Galaxy. This causes the distortion of the Galactic magnetic field and eventually leads to the expansion of a magnetic bottle, in which these particles are trapped for some period. The radio anomaly may be accounted for in terms of these relativistic electrons in an earlier stage, while the anisotropy may be due to the heavy nuclei in a later stage. If this interpretation is taken for granted, this provides an example of the active effect of cosmic rays on the Galactic magnetic field and may be regarded as an evidence for mixing between the disk and the halo by the cosmic ray pressure, as mentioned in (I-1).

(E-3) *Interstellar clouds and the formation of stars*[24].

It has recently been recognized that cosmic rays are not only of relativistic energies but also of non-relativistic ones, as observed in solar protons. These low energy particles rapidly lose their energy by the ionization process, so that they can heat up HI clouds which may be otherwise cooled down to a temperature as low as 20°K. The heating rate for maintaining the cloud temperature as high as 100°K can be accounted for in terms of their energy spectrum reasonably extrapolated from the relativistic energy region.

More information on the energy spectrum may be obtained by connecting the above heating mechanism with the formation of stars. If the energy of such a particle is not high enough to reach the central part of the cloud, its inner core becomes so cold that it begins to unstable against the gravitational contraction. Thus the stellar cluster is formed in the inner part of an HI cloud. The observed masses of an HI cloud and a stellar cluster suggest that the energy spectrum of low energy protons may have a peak at about 1 MeV.

The above discussions seem to emphasize the active significance of cosmic rays in our Galaxy. The same may be true in galaxies general; cosmic rays play different roles depending on their evolutionary stages.

References

1) V. L. Ginzburg and S. I. Syrovatsky: Prog. Theor. Phys. Suppl. No. **20** (1961) 1.
2) S. Fukui, S. Hayakawa, H. Nishimura and H. Obayashi: OR III-3-5.
3) S. Hayakawa, K. Ito and Y. Terashima: Prog. Theor. Phys. Suppl. No. **6** (1958) 1.
4) H. Aizu, Y. Fujimoto, S. Hasegawa, M. Koshiba, I. Mito, J. Nishimura and K. Yokoi: Prog. Theor. Phys. Suppl. No. **16** (1960) 54.
5) M. V. K. Appa Rao and M. F. Kaplon: CO III-1-
6) J. E. Baldwin, OR III-3-7.
7) W. L. Kraushaar and G. W. Clark: CO III-1-1.
8) P. Morrison, *Handbuch der Physik*, Vol. **46** (1960) p. 1.
9) T. Matano, I. Miura and M. Oda: PR III-2-3. S. Higashi, T. Kitamura, Y. Mishima, S. Miyamoto, H. Shibata and Y. Watase: PR III-2-4.
10) S. I. Syrovatsky: See ref. 1.
11) S. I. Syrovatsky: JETP. **41** (1961)
12) W. F. G. Swann: OR III-3-9.
13) H. O. G. Alfvèn: OR III-Concluding Remark.
14) Y. Ono and S. Sakashita: OR III-3-1, Bull. Astro. Soc. **13** (1961) 146.
15) S. A. Colgate and M. H. Johnson: Phys. Rev. Letter, **5** (1960) 235: S. A. Colgate, W. H. Grasberger and R. H. White: OR III-3-2.
16) S. Hayakawa, C. Hayashi and M. Nishida: Prog. Theor. Phys. Suppl. No. **16** (1960) 169.
17) G. R. Burbidge: Lecture given at the "Astrophysics" session.
18) E. M. Burbidge and G. R. Bridge: OR III-3-3.
19) H. Aizu and M. Koshiba, CO III-1-10.
20) J. Earl: Phys. Rev. Letter, **6** (1961) 125, P. Meyer and R. Vogt: Phys. Rev. Letter, **6** (1961) 193, see, also C. L. Critchfield, E. P. Ney and S. Oleska: Phys. Rev. **85** (1952) 461.
21) S. Hayakawa and H. Okuda: discussions presented in connection with OR III-3-7.
22) N. M. Gerasimova, A. I. Nikishov, and I. L. Rosential: OR III-3-8.
23) M. Oda and H. Hasegawa: OR III-3-6.
24) T. Hatanaka, S. Hayakawa, S. Nishimura, K. Takayanagi and W. Unno: OR III-3-4.

Discussion

Burbidge, G. R.: Your arguments for low energy cosmic rays are based on the argument that if they did not produce heating in the clouds their temperature would fall about 20°K—lower than is observed. In what way do these calculations of the equilibrium of clouds differ from those of Spitzer and Kahn who obtained temperature of HI clouds in reasonably agreement with observation.

Hayakawa, S.: If the heating were due to the collisions of clouds, the cloud temperatute would distribute over a wide range, say from about 1000°K right after the collision to about 20°K when it gets cooled down. As far as I know, such a wide distribution was not observed.

Lüst, R.: Could the calculations of shock wave in supernova show something about the efficiency of the production of cosmic rays?

Hayakawa: The present stage of such theories is still far from saying something more concrete about the origin of cosmic rays.

Shapiro, M. M.: The theory of supernova origin seems to be based on rather indirect evidence—namely the relatively high abundance of heavy elements. This is inferred from the theory of nuclear synthesis in the so-called *r*-process. But direct spectroscopic evidence about heavy elements in the supernova remnants is lacking.

Burbidge, G. R.: We believe that the *e*-process and *r*-process elements are produced in supernovae. But it is exceedingly difficult to interpret supernova spectra because of the effects other than abundance effects which we undoubtedly present.

Davis, L. Jr.: It can be argued against the supernova theory of the cosmic rays that currently supernovae do not seem to occur in our Galaxy as a high enough rate. It can be argured against the Fermi theory that the gas velocities are not high enough currently to make it work. If the cosmic rays can be stored in the Galaxy for most of its age, they could have originated early in its evolution, a time when astronomical evidence strongly suggests that its activity was much greater than it is today. Thus at that time there should have been enough turbulent to make the Fermi mechanism work (and there might have been more supernovae).

Peters, B.: It seems possible in principle to find out whether cosmic ray intensity has undergone appreciable changes. Present data on the contents of spallation products in iron meteorites, while not yet conclusive, suggest that cosmic radiation has remained essentially at its present level of intensity of for perhaps 2×10^9 years. One may expect more definite information going further back in time in the coming years.

Hayakawa: If the age of cosmic rays were as long as 10^{10} years, heavy nuclei such as iron would be destroyed by the collision with interstellar matter, even if the halo were empty.

Shapiro: Prof. Davis may underestimate the frequency of supernova outbursts in our Galaxy. The oft-quoted value of once in 300–400 years based on the outbursts which occured in the neighbourhood of the solar system, should be corrected for the large volume in the Galactic disk in which any outbursts have gone undetected. Then the frequency is once in several decades. This value is supported by the observations of supernova outbursts in other spiral galaxies.

CONCLUDING REMARKS Alfvén, H. O. G.: The only papers about the origin which have been presented at the conference refer to the supernova theory. However, they should not be taken as an indication that this theory is generally accepted. On the contrary, I think that it meets with insuperable difficulties.

It has never been seriously suggested that a supernova can produce the highest energies (say $>10^{15}$ eV). There are no reasons to doubt that it does generate low and medium energies ($<10^{15}$ eV) but I think that it is unlikely that very much of the cosmic rays we observe could have this origin. The real difficulty with the supernova theory is how the particles would travel from the supernova to us. Even if the supernova and we were situated on the same line of force which is not very likely—

we would only receive a few particles. The transport through space of a considerable number of cosmic ray particles produces electromagnetic effects which must be taken into consideration. No mechanism of transport has been suggested so far and I doubt that any mechanism exist.

Thus there are two objections against the supernova theory:

1. It can produce low and medium energy particles but these cannot reach us.
2. High energy particles could reach us but a supernova cannot produce them.

If the supernova theory is unacceptable, how should we then explain the origin of cosmic radiation? I think that acceleration of particles should be considered as a normal property of matter in space both in the magnetosphere of the earth, interplanetary space, interstellar space and intergalactic space. The acceleration is due to the variations of the magnetic fields and the most important mechanism is probably what the plasma physicists now call magnetic pumping. At the Moscow Conference a paper was presented in which a detailed theory of this process was given. This paper was not given rise to any discussion as far as I know, it is not included in Professor Hayakawa's survey, and seems to have been completely forgotten.

According to the theory most of the cosmic ray which we observe in the energy range below say 10^{11} eV is produced by processes in interplanetary space, which explains the strong dependence on the solar activity. Similar local sources are formed around many stars (including the supernovae), and the particles they inject are further accelerated in interstellar space. The highest energies may be produced in part in intergalactic space.

We know that in the Earth's magnetic field there are processes which accelerate the particles in the outer radiation belt. It is natural to assume that similar processes should take place in the Sun's magnetic field, and according to the theory they should accelerate the low energy part of the cosmic radiation. Hence we could consider that as the Van Allen radiation belt of the sun. It is of interest to note that we should not expect the cosmic radiation to have the same chemical composition as the interplanetary matter, because for reasons discussed in the paper the accelerating mechanism should be much effective to the heavier elements.