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FINAL TECHNICAL REPORT

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COSMIC PHYSICS DATA ANALYSIS PROGRAM

1 March 1992 to 28 February 1993

FOR

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ABSTRACT

A data analysis program under terms of the NASA Grant has been carried out to investigate the intensity, propagation and origin of primary Cosmic Ray Galactic electrons. Scanning was carried out on two new balloon flight experiments as well as the border area of previous experiments. The identification and evaluation of the energies of the primary electrons were carried out. A new analysis of these data were incorporated into an overall evaluation of the roll of electrons in the problem of the origin of cosmic rays.

Recent measurements indicate that the earth may be within the expanding Geminga supernova shock wave which is expected to have a major effect upon the propagation and the energy spectrum of galactic electrons. Calculations with the Geminga model indicate that the cut-off energy may be very close to the observed highest energy electrons in our analysis.

I. INTRODUCTION

The discovery of primary galactic electrons by Earl and Meyer and Voght in the year 1961 [1] opened up a field of research which has been of great value in the study of the origin of cosmic rays in general. In the 23rd International Cosmic Ray Conference, Calgary, 19-30 July, 1993, there was a good deal of discussion and papers on the possible origin and spectrum of cosmic rays. In the case of galactic electrons knowledge of their energy spectrum, largely through our work, is know to energies of about 2,000 Gev [2]. The problem of the origin of galactic electrons has to be approached by way of models dependent on the theory of energy loss and propagation of electrons in interstellar space. Reasonable assumptions on the energy loss make it almost certain that electrons of energies of the order of 1,000 GeV must have origins closer that 1,000 pc from the earth. The most likely sources would be acceleration by shock waves from supernova remnents. When these assumptions have been utilized in diffusion and leaky box models [2], the energy spectrum at the source is calculated to be $N(E) \sim E^{\Gamma} = E^{-2.4}$. The research conneted with our Data Analysis grant has been directed to increasing the statistical precision of our data through additional scanning and analysis. The most important objective has been to determine if there is an upper limit on the energy of galactic electrons.

II. DATA ANALYSIS PROGRAM

The data analysis research for this Grant made use of the Galactic balloon flight experiments listed in Table I. All available area of the detectors have now been examined and are complete for electron energies over 600 GeV. The energy determination of each electron was made and treated statistically as shown in Table II.

TABLE I

Balloon flight experiments for the study of Galactic Electrons.

FLIGHT (year)	Area m**2	Altitude mb	EXPOSURE FACTOR* (M**2)*hrs*sr	LAUNCH SITE
1968	0.05	6.0	.51	Haranomachi, Japan
1969	0.05	7.0	.36	Haranomachi, Japan
1970	0.05	6.0	1.52	Sanriku, Japan
1973	0.20	8.0	3.37	Sanriku, Japan
1976	0.40	3.9	19.7	Palestine, Texas
1977	0.78	4.4	44.2	Palestine, Texas
1979	0.80	4.0	43.3	Palestine, Texas
1980	0.80	4.6	52.3	Palestine, Texas
1984	0.15	9.2	3.0	Sanriku, Japan
1985	0.31	9.5	9.6	Sanriku, Japan
1988	0.15	6.9	3.3	Uchinoura, Japan
1990	0.80	3.7	56.	Fort Sumner, New Mexico
1990	0.24	3.0	78.	McMurdo, Antarctica

The emulsion chamber type detector used in these experiments provides the most suitable instrument to measure primary electrons for the following reasons as described in the ref. [2]. Namely those are the naked eye detection with the aid of sensitive X-ray films, precise incident particle identification, accurate energy determination and large effective area with the wide acceptance angle of the detectors. The flight conditions and exposure factor excluding the edge area are summarized in Table 1.

TABLE II

Energy bin (GeV)	$<E>$ (GeV)	$S\Omega T$ (m^2 sr s)	N_{ob}	N_{prt}	Flux (J) (m^2 sr s GeV$)^{-1}$	$E^3 \times J$
1500 ~ 3000	2068	5.888×10^5	10	5.6	$(6.42 \pm 4.29) \times 10^{-9}$	57 ± 38
1000 ~ 1500	1214	5.888×10^5	14	7.6	$(2.59 \pm 1.50) \times 10^{-8}$	46 ± 27
800 ~ 1000	892	4.703×10^5	15	9.6	$(1.03 \pm 0.46) \times 10^{-7}$	73 ± 33
600 ~ 800	690	8.011×10^4	8	6.3	$(3.96 \pm 1.91) \times 10^{-7}$	130 ± 63
400 ~ 600	486	2.259×10^4	7	5.0	$(1.12 \pm 0.65) \times 10^{-6}$	128 ± 74
300 ~ 400	345	2.259×10^4	9	6.4	$(2.87 \pm 1.43) \times 10^{-6}$	118 ± 59
200 ~ 300	243	8740	7	5.5	$(6.32 \pm 3.30) \times 10^{-6}$	91 ± 47
150 ~ 200	172	1679	3	2.7	$(3.22 \pm 2.53) \times 10^{-5}$	164 ± 128
100 ~ 150	121	1679	8	7.2	$(8.61 \pm 3.45) \times 10^{-5}$	153 ± 61
60 ~ 100	75.8	682	9	9.0	$(3.30 \pm 1.17) \times 10^{-4}$	144 ± 51
30 ~ 50	37.9	69.8	6	6.0	$(4.30 \pm 1.92) \times 10^{-3}$	234 ± 105

Our emulsion chamber is consists typically of a stack of 24 detection layers. Each layer is made up of an emulsion plate. X-ray films and a lead plate. The emulsion plate used for shower trace-backs. the identification of incident particles and electron track counting under a microscope is a plate of 500 μm-thick acrylic. coated on both sides with 50 μm-Fuji-ET7B emulsion. X-ray films are used for detection of shower events. and track reconstruction through the chamber. For this. we now use high sensitivity screen-type X-ray films. such as Fuji G8-. G12- and newly provided GS-RXO [3] which are combinations of Gd_2O_2S:Tb phosphor screen and a green sensitive Fuji X-ray film. The detection threshold of these X-ray films is improved to about 150 GeV.

The thickness of the lead plates increases from 0.5 mm to 5.0 mm with observational depth. A radio command flipper is used to keep the detector inverted during ascent and descent of the balloon. The cross-sectional area and total depth of the detector were 20 × 25 cm^2 and 8.2 radiation lengths [r. 1] until 1973. and increased to 40 × 50 cm^2 with the same depth thereafter. The acceptance angle of our detector is as large as 60° from the vertical direction so that the total analyzed exposure factor becomes 588.818 [m^2 sr sec] excluding the area of unfavorable conditions that was not used in the analysis. The detection of shower events is made by naked eye scanning on all layers of X-ray films. Those detected showers are traced throughout the chamber on the corresponding emulsion plates by microscope-scanning. Identification of the shower initiating particle is made by examining the details of the starting point and shower development of the event under the microscope [2]. The energy of the electron is determined by counting the shower tracks within a circle of 100 micron radius as described in the ref. [2]. The number of shower tracks is related to electron energy through the three-dimensional shower theory [4], which is also calibrated by the electron beam of FNAL. The error of this energy determination is typically less than 10 % [2].

The contribution of atmospheric secondary electrons is carefully examined under Approximation A of Cascade Theory [4] by using the observed data of the atmospheric γ-ray spectrum. The observed spectrum above 30 GeV [2] normalized at 4 gr/cm^2 is

$$\Gamma(E) = (1.20 \pm 0.20) \times 10^{-4} (100\ \mathrm{GeV}/E)^{2.75 \pm 0.10}\ /\mathrm{m}^2\ \mathrm{sr\ sec\ GeV}. \quad (1)$$

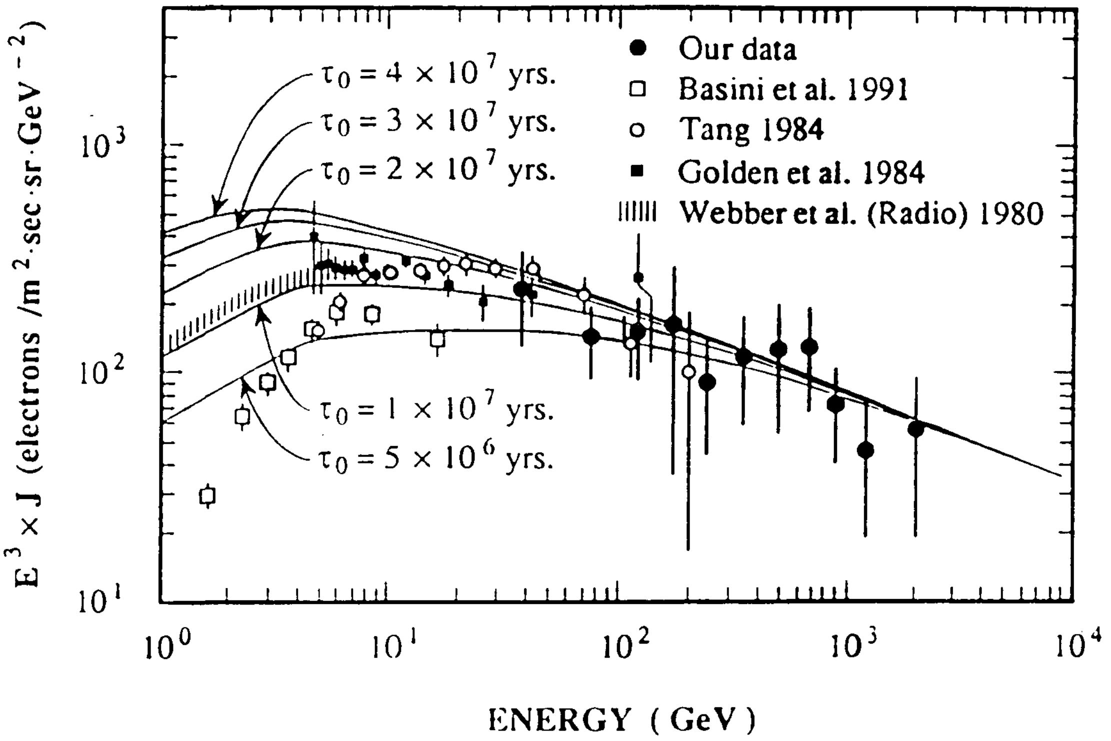
This γ-ray flux is consistent with the μ meson flux observed at underground by assuming γ-rays and μ mesons are produced from the decay of π^0 and $\pi^\pm$ mesons respectively, and assuming charge symmetry for the production of π mesons [2]. It is also to be noted that the method of detection and energy determination of the γ-rays are made in the same way and in the same chamber as that for the electrons, and the relative intensity of each flux is not subject to unexpected observational errors, even if they exist. Then the relative error of the estimate of secondary electrons to the observed electrons does not exceed that of γ-rays. In Table 2, the number of electrons observed by all of our experiments (N_{ob}) and the calculated primary electron number (N_{pri}) and flux values at appropriate observed energy intervals are listed according to their flight conditions.

In Fig. 1, the primary electron energy spectrum in the form of $E^3 \times$ flux, derived from all of our data, is shown along with the data of Golden et al. [5] and Tang [6] together with the results derived from the Galactic radio wave intensities [7, 8]. The resulting primary electron energy spectrum ($J_e(E)$) in the form of a power law is well represented by

$$J_e(E) = (1.5 \pm 0.3) \times 10^{-4} (100\ \mathrm{GeV}/E)^{3.3 \pm 0.1}\ /\mathrm{m}^2\ \mathrm{sr\ sec\ GeV}\ , \quad (2)$$

and is consistent with our previous data [2].

Fig. 1



The observed spectrum is analyzed by referring to both the Leaky Box Model and Nested Leaky Box Model with the following assumptions:

1. Cosmic ray particles are produced in the source region with power law energy spectrum of the form: $N(E)\, dE = E^{-\gamma}\, dE$.
2. Energy loss of cosmic ray electrons above a GeV can be written as $dE/dt = -\, b\, E^2$, with $b = 1.02 \times 10^{-16}\ (W_{ph} + \langle H^2 \rangle / 8\pi)$ [GeV sec]$^{-1}$.

We take for the most probable value of b as 1.97×10^{-16} [GeV sec]$^{-1}$, by adapting 6.7 μG, (1.11 eV/cm^3), for the Galactic magnetic field [8], 0.26

eV/cm^3, 0.31 eV/cm^3 [9], and 0.25 eV/cm^3 for energy density of visible, infra-red and 3 K microwave respectively.

In the Leaky Box Model, the leakage life time τ is related the bending point, E_C as

$$E_C = [(\gamma - 1) b \tau_0 5^\delta]^{-1/(1-\delta)}, \text{ with } \tau = \tau_0 (5 \text{ GeV}/E)^\delta. \qquad (3)$$

The spectral index of the electrons far beyond the bending point is $\gamma + 1$ in this model, which is 3.3 ± 0.1 from the observed spectrum $J_e(E)$. However the energy range where we fit the spectral index is not far enough from the bending point. After correcting this factor we have the spectral index of 2.4 ± 0.1 for low energy side. The spectral index at the low energy side derived from the Galactic radio waves is 2.1 ± 0.1 [7]. We assume that $\delta = 0$ in the energy region of a few GeV as in the case of heavy primaries, and then we have 0.3 ± 0.14 in the energy region above several GeV. This value is a little smaller than those recent observed values of 0.4 – 0.6 derived from the protons and heavy primaries in cosmic rays [10, 11]. However, we have still reasonable agreement for the observed spectrum as shown in Fig. 1 by taking the following parameters of $\gamma = 2.4$, $\delta = 0.4$ ($E \geq 5$ GeV), $\delta = 0$ ($E < 5$ GeV), $\tau_0 = 1.3 \times 10^7$ yr, $b = 1.97 \times 10^{-16}$ [GeV sec]$^{-1}$ and $E_C = 12.8$ GeV.

Since synchrotron radiation by high energy electrons is observed from supernova remnants, it is quite plausible to assume that most of cosmic ray electrons are produced from SNR. In this case, we need to treat the propagation of electrons by the Nested Leaky Box Model. In order to see the effect of energy loss inside the source region, we introduce the parameter α, which indicates the degree of the energy loss inside SNR compared with that of Galaxy. Putting suffix s and G to those parameters in the SNR and Galaxy respectively, α is defined by $b_S \tau_S = \alpha b_G \tau_G$. When α is much smaller than unity, the bending point of the spectrum inside the source (E_{cs}) is larger than the bending energy (E_{cG}) due to the energy loss inside the Galaxy. In this case, the Leaky Box Model still gives a reasonable result up to a certain limited energy region below E_{cs}. Then the value of α is crucial in the treatment of the propagation for the Nested Leaky Box Model. The evaluation of α was made by Komori and Nishimura [8], by assuming that the electrons produced from SNR is in equilibrium to the leakage of the electrons from the Galaxy.

$$N_S(E)/\tau_S = N_G(E)/\tau_G \ , \qquad (4)$$

where $N(E)$ is the total number of electrons inside in each respective region. The ratio of total radio flux from each region, $F_S(\nu)/F_G(\nu)$, is calculated, by using the magnetic field strength of each region H_S and H_G, as

$$\frac{F_S(\nu)}{F_G(\nu)} = \left[\frac{N_S(E)}{N_G(E)}\right]\left[\frac{H_S}{H_G}\right]^{(\gamma+1)/2} = \left[\frac{\tau_S}{\tau_G}\right]\left[\frac{H_S}{H_G}\right]^{(\gamma+1)/2}$$

$$= \alpha\left[\frac{b_G}{b_S}\right]\left[\frac{H_S}{H_G}\right]^{(\gamma+1)/2} = \alpha\left[\frac{H_S}{H_G}\right]^{-2+(\gamma+1)/2} \qquad (5)$$

Komori and Nishimura made careful analysis for the observed ratio for $F_S(\nu)/F_G(\nu)$, obtaining the value of about 10^{-2}. Since the estimated maximum value of H_S is of the order of 10^{-4} Gauss, the value of H_S/H_G is estimated within the range between 1 and 100. Then we have a value ranging $\alpha = 0.01$ to 0.1 referring to the formula (5).

In the case of Nested Leaky Box Model, we have more free parameters, giving better agreement with the observed data than in the case of the Leaky Box Model. As an example, we show a good agreement with observed spectrum in Fig. 2, in which we take

$\gamma = 2.2$,	$\alpha = 0.05$,	$H_S/H_G \sim 10$,
$\delta_G = 0.6$ ($E \geq 5$ GeV),		$\tau_{0G} = 2 \times 10^7$ yr,
$\delta_G = 0$ ($E < 5$ GeV),		$\delta_S = 0.2 - 0.6$,

giving E_{cG} = 10.5 GeV, E_{cS} = 306 GeV – 18.7 TeV.

Fig. 2

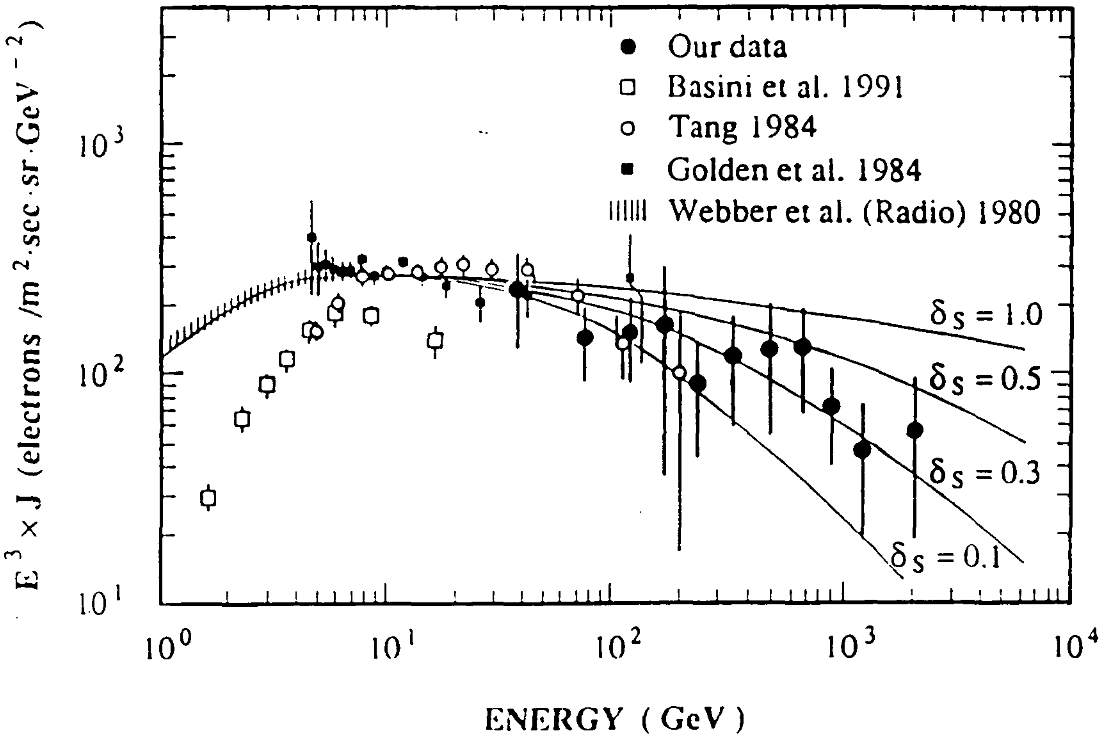
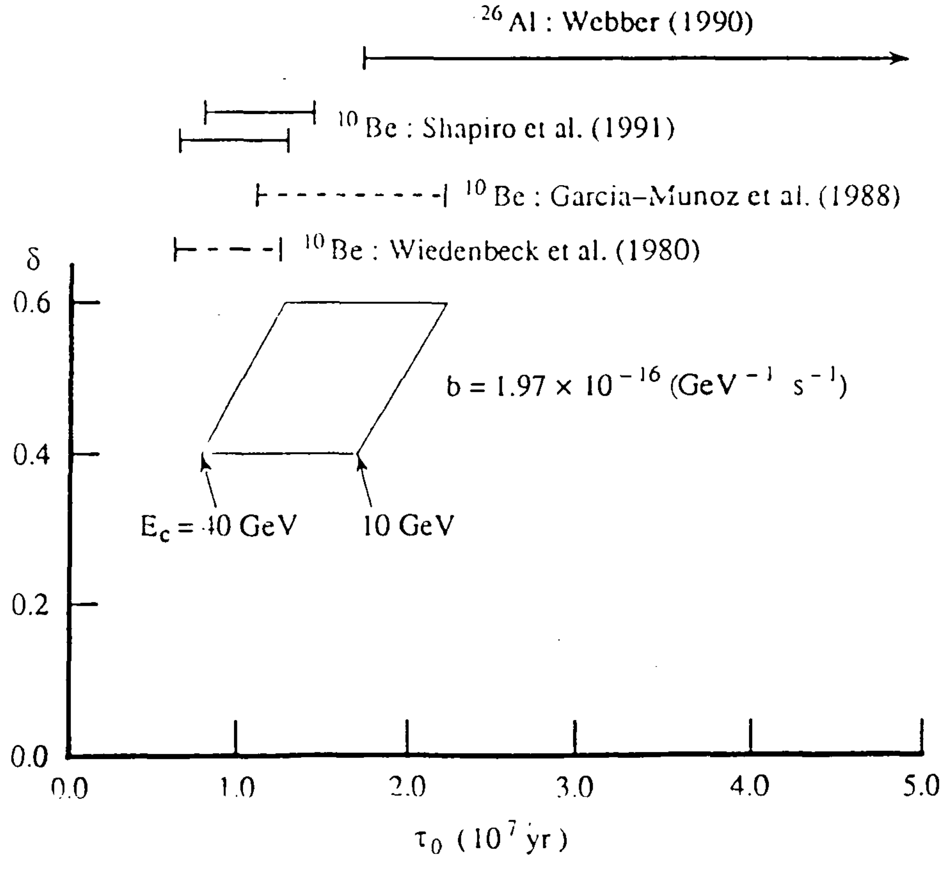

● Our data
□ Basini et al. 1991
○ Tang 1984
■ Golden et al. 1984
||||||| Webber et al. (Radio) 1980
$\delta_S = 1.0$
$\delta_S = 0.5$
$\delta_S = 0.3$
$\delta_S = 0.1$
$E^3 \times J$ (electrons /m^2·sec·sr·GeV^{-2})
10^1
10^2
10^3
10^0
10^1
10^2
10^3
10^4
ENERGY (GeV)

Fig. 3


^{26}Al : Webber (1990)
^{10}Be : Shapiro et al. (1991)
^{10}Be : Garcia-Munoz et al. (1988)
^{10}Be : Wiedenbeck et al. (1980)
δ
0.6
0.4
0.2
0.0
b = 1.97 × 10^{-16} (GeV^{-1} s^{-1})
E_c = 40 GeV
10 GeV
0.0
1.0
2.0
3.0
4.0
5.0
τ_0 (10^7 yr)

Taking this value for α, the bending point inside the source, E_{CS}, is expected to be much larger than the bending point in the Galaxy, E_{CG}. The Leaky Box Model gives the reasonable results below E_{CS}, and the arguments for the Galactic confinement time discussed by using the Leaky Box Model are justified.

The bending point of the observed spectrum, E_C, locates in the region ranging from 10 to 40 GeV as seen from Fig. 1 and 2. In this energy region, the Simple Leaky Box Model is still applicable, since the effect of the energy loss inside the source region is not appreciable as mentioned above. Assuming δ_G is 0.4 - 0.6, we have a relation of the cosmic ray confinement time in the Galaxy to bending energy as shown in Fig. 3, where we assume $b = 1.97 \times 10^{-16}$ [GeV sec]$^{-1}$ and $\gamma = 2.7 - \delta_G$.

We then have the values of the confinement time of

$$\tau_{oG} = (0.7 - 2.2) \times 10^{7}\ \text{yr} \quad \text{for} \quad \delta_G = 0.4 - 0.6,$$

$$\tau_{oG} = (1.3 - 2.2) \times 10^{7}\ \text{yr} \quad \text{for} \quad \delta_G = 0.6.$$

It is to be noted that the confinement life time obtained by the electron spectrum is accurate enough when compared to other isotope measurements. The results of the confinement time observed by the ratio of $^{10}\mathrm{Be}/^{9}\mathrm{Be}$ are ranging 6×10^{6} yr to 2.2×10^{7} yr [12]. A recent summary by Shapiro et al. suggested the most probable value of the confinement time to be $(0.79 - 1.43) \times 10^{7}$ yr or $(0.64 - 1.28) \times 10^{7}$ yr [13]. The results on $^{26}\mathrm{Al}/^{27}\mathrm{Al}$, $(4.1 \pm 2.4) \times 10^{7}$ yr, still suffers from large errors in the observed data.

The existence of electrons beyond 2 TeV indicates that they should have been produced within the past 10^{5} years or less since the energy loss of those electrons. It would then be expected that at higher energy regions beyond a few TeV, the primary electron spectrum has some bumps because of low probability of the supernova occurring in such short time intervals and at short distances for the solar system, if we assume that the origins of such electrons are supernova. Therefore, there is a possibility to identify nearby supernova sources from the high energy electron flux in this case [14].

III. DISCUSSION

One new idea for the origin came from data on the distance and age of the supernova remnant Geminga. Since Geminga may be only about 100 pc from the earth, the earth may actually be inside the expanding shock wave of the Geminga supernova explosion [15]. The study of Galactic electrons considering the Geminga model is especially important since the resulting flux is very dependent on the diffusion within the Geminga bubble. Although the bubble is about 100 parsec in diameter and the shock is probably now decaying, the calculated [15] energy spectrum of particles near the earth is close to that which is presently observed. However the maximum energy expected from acceleration by the Geminga shock is about 1,000 Tev for protons. Since all singly charged particles are accelerated to the same velocity by a shock, the maximum energy to be expected for the cosmic ray electrons would be about 0.5 to 1.0 TeV. The model leads to anisotropy of the particles in addition to a sharp cut-off in energy. The summary of our data to date [16] extends to an energy of 2 Tev with no sign of a cut-off. Cosmic ray electrons should be a good test of the model since they lose energy so rapidly that at 1 TeV they could not come from distances from the earth greater than about 1,000 pc.

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APPENDIX I

Proceedings of the 23rd International Cosmic Ray Conference
Calgary 19-30 July 1993; Vol. 2, page 128-131

Energy Spectrum and Confinement Time of Cosmic-ray Electrons

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ABSTRACT

The observations of primary electrons have been performed with emulsion chambers by 11 balloon flights since 1968. Including new data, we have an improved observed spectrum, ranging from 30 GeV to a few TeV, which is consistent with our previous data. Combing with other data, we derive the confinement time of electrons in the Galaxy. The result is $[0.7\text{-}2.2]\times10^7$yr, which is consistent with the recent observed data by radio isotope. For more detailed analysis of the electron spectrum, we discuss the constraint of the model based on the possible origin of super nova sources.

1 INTRODUCTION

Cosmic-ray electrons are revealing several important aspects of astrophysical significance. At a higher energy side beyond 1TeV, electrons can not travel far distance because of the synchrotron and inverse Compton losses. They must be produced within the past less than about 10^5 years and the sources should be nearby the solar systems. Extending the observations to further high energy side, it might be possible to identify the nearby sources, if electrons are in fact produced from the individual sources [1]. In the medium energy regions, say 10 to 100GeV, the spectrum bends by the synchrotron losses which gives us a clue for the confinement time of electrons inside the Galaxy. However because of the difficulty of the observations, the definitive conclusion was difficult to be derived.

We first describe our recent observations on the electron spectrum. Analyzing the spectrum combining with other data, we derive the confinement time on the basis of Leaky Box Model. However, since synchrotron radiation by high energy electrons from Super Nova Remnants is observed, it is quite possible that at least a certain fraction of the electrons is produced from SNR. We then estimate this effect in the scheme of Nested Leaky Box Model by analyzing the relative intensity of the radio flux from SNR and the Galaxy. The results indicate the effect is minor to discuss the confinement time of electrons in the Galaxy.

2 OBSERVATIONS

After our previous paper [2], we continued the observation of primary electrons by balloon-borne emulsion chambers. Summarizing 11 flights since 1968, the total effective exposure factor becomes 588.848 (m^2 sr sec) excluding edge area that was not used in the analysis. The emulsion chamber used in these experiments provides the most suitable instrument to measure primary electrons. Namely, it permits efficient detection of events with the aid of high sensitive X-ray films. Also it allows precise incident particle identification, accurate energy determination and a large effective area of the detectors with a large acceptance. Our emulsion chamber consists typically of a stack of 24 detection layers. Each layer is made up an emulsion plate, X-ray films and a lead plate. We now incorporate high sensitivity screen-type X-ray films, such as Fuji G8-, G12- and newly provided GS-RIO [3] which are combinations of Gd_2O_2S:Tb phosphor screen and a green sensitive Fuji X-ray film. The detection threshold of these X-ray films is improved to about 150 GeV.

The contribution of atmospheric secondary electrons is carefully examined under Approximation A of Cascade Theory by using the observed data of the atmospheric γ-ray spectrum [2]. In Figure 1, primary electron energy spectrum in the form of $E^3\times$Flux, derived from all of our data, is shown along with the data of Golden et al.[4] and Tang [5] together with the results derived from the Galactic radio wave intensities [6].

The resulting primary electron energy spectrum, $J(E)$, in the form of a power law is well represented by

$$J(E)=(1.5\pm0.3)\times10^{-4}\,[100\mathrm{GeV}/E]^{3.3\pm0.1}\ [\mathrm{m^{-2}sr^{-1}sec^{-1}GeV^{-1}}]. \qquad (1)$$

and is consistent with our previous data [2].

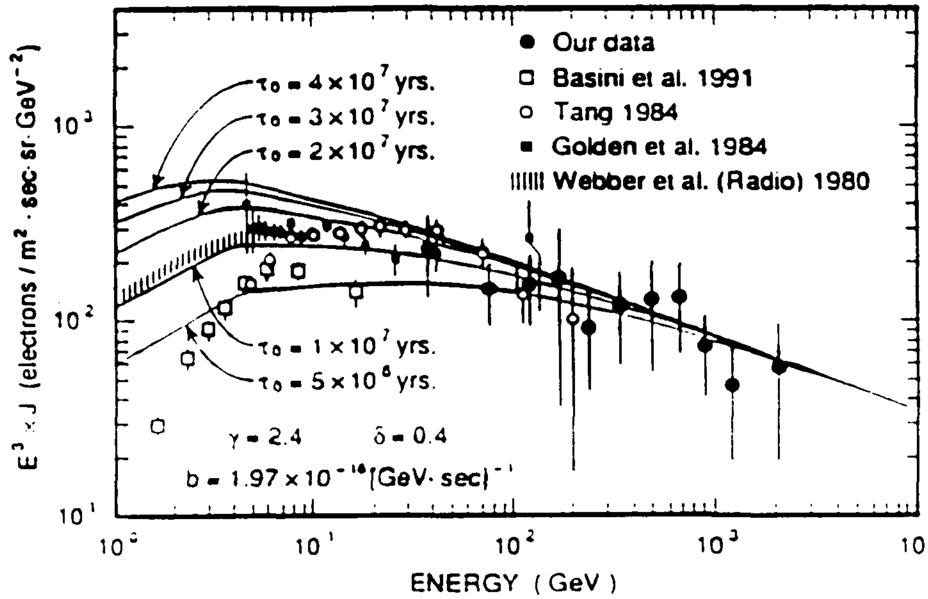

Fig. 1 . Observed Spectrum of Cosmic-ray Electrons. Solid line is due to the LBM.

3. THE CONFINEMENT TIME OF ELECTRONS INSIDE THE GALAXY

From the spectrum shown in Fig. 1, it is most likely the bending of the spectrum exists between 10GeV and 40GeV, although the statistics of the data are not good enough. Assuming the leaky box model, we have a relation of the cosmic ray confinement time in the Galaxy to this bending energy as shown in Figure 2.

Here we assume

1. Cosmic ray electrons are produced in the source region with power law energy spectrum of the form: $N(E)dE = E^{-\gamma}dE$
2. Energy loss of cosmic ray electrons above a GeV can be written as
   $dE/dt = -bE^2$, with $b = 1.02\times10^{-16}\,(W_{ph} + \langle H^2\rangle/8\pi)$ [GeV sec]$^{-1}$

We take for the most probable value of b as 1.97×10^{-16} [GeV sec]$^{-1}$, by adapting 6.7 μG[1.11 eV / cm^3] for the Galactic magnetic field [6], 0.26eV /cm3, 0.31eV /cm^3 [7], and 0.25 eV/cm^3 for energy density of visible, infra-red and 3 K microwave respectively.

In the Leaky Box Model, the leakage life time τ is related the bending point, Ec as

$$E_c = [(\gamma-1)b\tau_o 5^{\delta}]^{-1/(1-\delta)} \quad \text{with} \quad \tau = \tau_o\,(5\mathrm{GeV}/E)^{\delta}.$$

Taking the value of spectral exponent, γ, as $\gamma = 2.7 - \delta$, we have the confine time of

$$\tau_o = (0.7\text{-}2.2)\times10^7\ \mathrm{yr} \qquad \text{for} \qquad \delta = 0.4\text{-}0.6$$
$$\tau_o = (1.3\text{-}2.2)\times10^7\ \mathrm{yr} \qquad \text{for} \qquad \delta = 0.6$$

It is to be noted that the confinement life time obtained by the electron spectrum is accurate enough when compared to other isotope measurements. Observations of the ratio of ^{10}Be / ^{9}Be have been performed by various authors, and results of the confinement time are scattered ranging 6×10^6 yr to 2.2×10^7 yr [8]. A recent summary by Shapiro et al [9] combining all observed data by putting appropriate weight to each datum suggested the most probable value of the confinement time to be

$$(0.79\text{-}1.43)\times10^7\mathrm{yr} \quad \text{or} \quad (0.64\text{-}1.28)\times10^7\ \mathrm{yr}$$

depending on the cross sections of this reaction. The confinement time as derived from ^{26}Al / ^{27}Al, $(4.1\pm2.4)\times10^7$ yr, still suffers from large errors in the observed data.

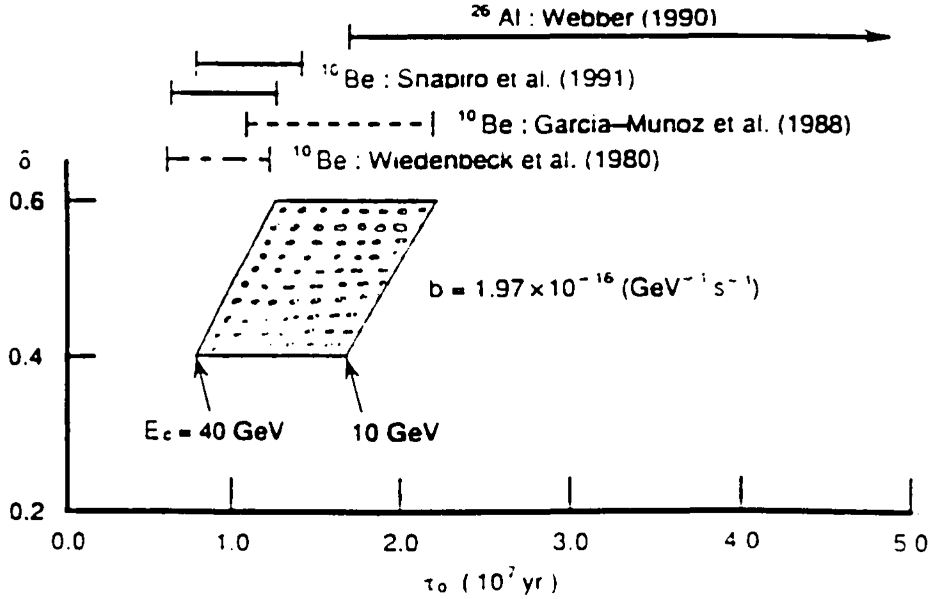

Fig. 2 The Relation of the Confinement Time and the Bending Energy

4. PROPAGATION MODEL

4.1 Leaky Box Model

As for the spectral fitting , we have a reasonable agreement for the observed spectrum as shown in Fig. 1 by taking the following parameters of

$\gamma = 2.4$ $\delta = 0.4$ $\tau_0 = 1.3 \times 10^7$ yr

$b = 1.97 \times 10^{-16}$ [GeV sec]$^{-1}$ · yielding $E_c = 12.8$ GeV

4.2 Electrons from SNR

Since the synchrotron radiation by high energy electrons is observed from supernova remnants, it is plausible to assume that at least a certain fraction of cosmic-ray electrons is produced from SNR. In this case, we need to treat the propagation of electrons by the Nested Leaky Box Model, and need to take into account of the effect of energy loss inside the source region. In order to see the effect clearly, first we assume the extreme case that all cosmic-ray electrons are produced inside the SNR and diffuse out to the Galactic space. The important parameter in this case is α which indicates the degree of the energy loss inside SNR compared with the loss inside the Galaxy. Putting suffix S and G to those parameters in the SNR and Galaxy respectively, α is defined by :

$$b_S \tau_S = \alpha b_G \tau_G \tag{2}$$

When α is much smaller than unity, the bending point of the spectrum inside the source (E_{cS}) is larger than the bending energy (E_{cG}) due to the energy loss inside the Galaxy. In this case, the Leaky Box Model still gives a reasonable result up to a certain limited energy region below E_{cS} Then the value of α is crucial to estimate the effect of the propagation inside the source in the Nested Leaky Box Model. The evaluation of α was made by Komori and Nishimura [6], by assuming that the electrons produced from SNR is in equilibrium to the leakage of the electrons from the Galaxy.

$$N_S(E) / \tau_S = N_G(E) / \tau_G , \tag{3}$$

where N(E) is the total number of electrons inside each respective region. The ratio of total radio flux from each region, $F_S(\nu) / F_G(\nu)$ is calculated, by using the strength of magnetic field of H_S and H_G ineach region as

$$F_S(\nu)/F_G(\nu) = \{N_S(E)/N_G(E)\}\{H_S/H_G\}^{(\gamma+1)/2} = (\tau_S/\tau_G)(H_S/H_G)^{(\gamma+1)/2}$$
$$= \alpha\{b_G/b_S\}\{H_S/H_G\}^{(\gamma+1)/2} = \alpha\{H_S/H_G\}^{-2+(\gamma+1)/2} \quad (4)$$

Komori and Nishimura made careful analysis for the observed ratio for the radio flux of $F_S(\nu)/F_G(\nu)$, obtaining the value of about 10^{-2}. Since the estimated maximum value of H_S is of the order of 10^{-4} Gauss, the value of $\{H_S/H_G\}$ is estimated within the range between 1 and 100. Then we have a value of $\alpha = 0.01 - 0.1$ referring to the formula (4).

In the case of Nested Leaky Box Model, we have more free parameters, giving better agreement with the observed data than in the case of the Leaky Box Model. As an example, we show a good agreement with observed spectrum in Fig. 3.

Taking this estimated value for α of 0.01 to 0.1, the bending point inside the source, E_{CS} is much larger than the bending point in the Galaxy, E_{CG} The Leaky Box Model gives the reasonable results below E_{CS} and the arguments for the Galactic confinement time discussed by using the Leaky Box Model are justified.

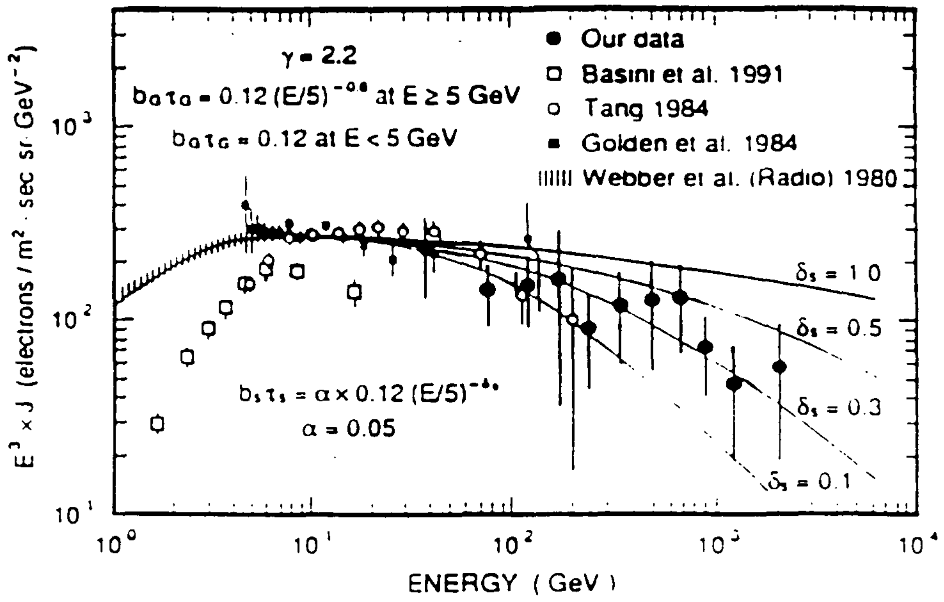

Fig. 3 : Spectral Fitting by the Nested Leaky Box Model

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