UBSERVATION OF PRIMARY ELECTRON SPECTRUM AND ITS ASTROPHYSICAL SIGNIFICANCE

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ABSTRACT

Cosmic-ray electrons lose their energy by synchrotron and inverse Compton processes during their propagation through the Galaxy. Then it has been recognized that the spectrum of electrons brings us unique information for the propagation and acceleration of cosmic-rays. First, we discuss our recent observations to improve the statistics of our electron data beyond several hundred GeV with emulsion chambers and furthermore with a new instrument using scintillating fibers. Some results of a new exposure by balloons and the identification of the electrons beyond 1TeV are discussed. Astrophysical importance is emphasized for the electron spectrum in TeV region in relation to the contributions of nearby sources and to the propagation parameters.

INTRODUCTION

Cosmic-ray electrons beyond 1TeV lose almost of their energy through synchrotron and Compton processes during the propagation from the source within a time scale of 10^5 yrs. They can not travel far distance from the sources. It has been now recognized that the high energy electrons beyond 1TeV bring us unique information of cosmic-ray sources and propagation in the Galaxy.

In the last meeting, we reported the electron spectrum observed by emulsion chambers (Nishimura et al., 1995). In order to obtain the electron spectrum with better statistical precision, a new long duration exposure was performed from Sanriku Balloon Center in the fall of 1996. Some improvement of the statistics of the spectrum including new data is reported. For the electron initiated showers beyond 1TeV, we found the starting point distribution deviates from what expected by the Bethe Heitler cross-sections for radiation and pair creations. However, it agrees well if we include the Landau Pomeranchuk (LPM) effect. This is also an evidence of our accurate identification of the electrons among the proton components. We also refer to our recent observations by a new detector, which has been developed by replacing emulsion part with scintillating fibers. It is promising as an advanced detector for TeV electrons and observations of anisotropy of cosmic-ray electrons. Details of this balloon borne electron telescope with scintillating fibers (BETS) is reported in a separate paper in this meeting (Torii et al., 1995, 1996).Since high energy electrons can not travel far distance, number of contributing sources decreases progressively with electron energy. One would expect a large fluctuation in the spectrum at high energy end and also the anisotropy of the electron flux.

Recent observations of non thermal X-rays from SN 1006 by ASCA satellite as well as the detection of TeV gamma-rays from this source by Cangaroo group give a strong evidence of the super nova origin of these high energy electrons. The absolute flux of observed electrons can well be explained if we assume similar amount of electrons is accelerated in each SN explosion as SN 1006.

We discuss the contributions of nearby sources referring to the recent list of the SNRs and Pulsars. The spectral shape also depends on the propagation parameters, and indicates that the observations of high energy electrons are important to resolve the problem of the propagation models.

OBSERVATIONS OF HIGH ENERGY ELECTRONS

We have observed 14 electrons beyond 1TeV with total exposures of $6.8m^2$str.day in the past experiments. The flux of primary electrons is about $2/m^2$str.day beyond 1 TeV. The ratio of electrons to protons decreases progressively with energy, and becomes 0.1% at around 1 TeV. To observe electrons in this energy region, we need a detector of large $S\Omega$ with high rejection power to abundant proton components. The emulsion chamber is a stack of the emulsion and lead plates,and has several merits over other detectors. It has a large acceptance solid angle with a large rejection power against to cosmic-ray protons by inspecting the shower at starting point. Energy determination is accurately made by counting shower particles within a small radius from the shower axis. Thus the total depth of the detector is relatively small for the shower development and the detector weight is reduced. The scanning problem is resolved by naked eye scanning with screen type X-ray films (phosphoric plates with high sensitive photographic films) on the nuclear emulsion plates, and we can locate the shower in the emulsion plates.

To increase the statistics of number of observed electrons beyond 1TeV, a new exposure was made from Sanriku Balloon Center in September 1996. The size of the emulsion chamber is 40cmx50cm, floating for about 35hrs at an altitude of 37.4km (4.5mb). Full analyses have been completed beyond 800GeV.

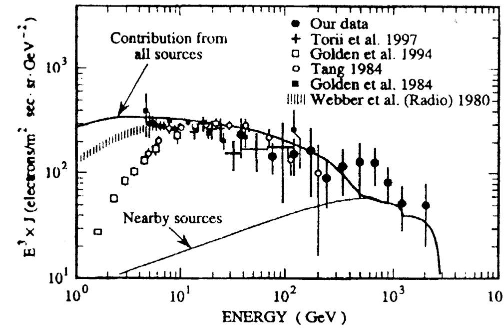
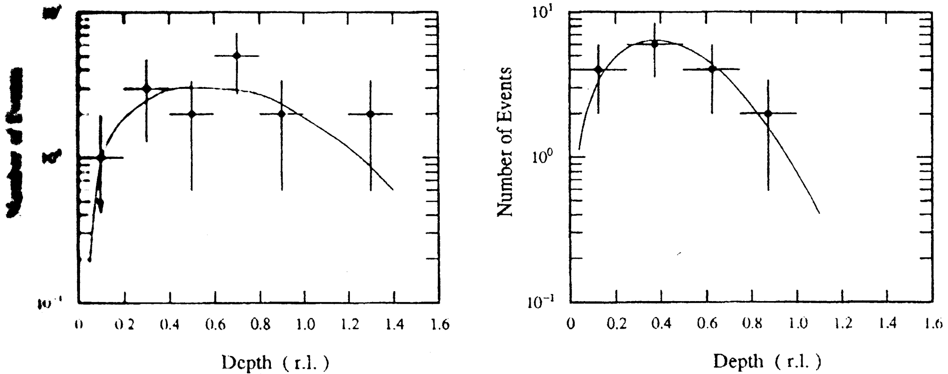


Fig.1. Observed Spectrum of Cosmic Ray Electron.



a) Electrons showers beyond b) 1TeV Electron showers with energy around 100GeV

Fig. 2. Starting point distribution of electron showers observed in emulsion chamber.

An analysis with threshold of 600 GeV with X-ray film scanning is made in half an area at the time of this writing. We found 4 electrons beyond 800GeV and 6 beyond 600GeV, being consistent with the spectrum so far obtained. The observed spectrum including new data is shown in Fig. 1. We also make an analysis of electrons around 100GeV by microscope scanning, since this is an excellent exposure. The statistics of electron data at 100GeV region will be much improved by the time of this meeting,

The most important point of the electron observation is the identification of electron initiated showers from those initiated by cosmic ray protons particularly in TeV region. For a cross check of our identification, we see the starting point distribution of electron initiated showers. The starting point distribution, P(t)dt, in which the first pair electron appears between t and t+dt are given by,

$$P(t)\,dt = e^{-\frac{\sigma}{2}t^2 \ln(Eo/E)} \quad \sigma\ t\ln(Eo/E)dt,$$

where σ is the cross-section of pair creation, Eo the energy of incident electron, E the threshold of pair electron energy and t is measured in radiation lengths (Nishimura et al., 1980).

In the energy region of 100GeV, the Bethe-Heitler cross-section is applicable. However, in TeV region the reduction of the cross-section by LPM effect (Migdal, 1956, Fowler et al., 1959) changes the distribution of the starting point of the showers. We calculate of the starting distribution including LPM effect. Comparison of the observed data with theoretical expectations in both 100GeV and TeV region are shown in Fig. 2. We see clearly LPM effect in TeV region. We believe that these agreements with the theoretical prediction indicate the consistency of our identification of the electron initiated showers.

One of the difficulties of emulsion detectors is the accumulation of the background tracks, which limits the exposure time. Also it has usually no timing information, and can not be used to observe the anisotropy of the electrons. To resolve this problem, a new detector is developed with scintillating fibers by replacing the emulsion plates in the emulsion chamber. This can be used for observations of long exposures. The profiles of the electron showers are observed by image intensifier, and the data are

development stage, we put emulsion plates with scintillating fibers to see the completeness of the identification of electrons by this scintillating fibers. We found that the identification was almost complete. Preliminary data obtained by the test flight with this chamber is also shown in Fig. 1, which is consistent with the data so far obtained. To improve the system of this detector we schedule experiments using accelerator beams of high energy electrons and protons and further tests flights by balloons.
A final target is to perform long exposures for many days or a few yrs with space station and/or very long duration balloon exposures to observe electrons beyond 1 TeV of high statistical significance.

ASTROPHYSICAL SIGNIFICANCE OF HIGH ENERGY ELECTRONS

So far it has been recognized that the acceleration of the high energy electrons is related to Super Nova explosion. Strong evidence of SN origin of high energy electrons is given by ASCA observations of non thermal X-rays from SN1006 (Koyama, et al., 1995). Combining ASCA data with the data of soft X-rays and radio, it was concluded that the high energy electrons are accelerated inside SN 1006. The energy is extending up to 100 TeV with a power law spectrum of spectral index of 2.2 (Reynolds, 1996, Willingale et al., 1996). In this case we would expect TeV gamma-rays from this SNR through inverse Compton process with cosmic background microwave (Pohl, 1996, Mastiachiadis & de Jager, 1996). Recent observations of Cangaroo group have succeeded the detection of the TeV gamma rays from SN 1006, and proved the existence of high energy electrons up to around 100TeV (Tanimori et al., 1997).
The total flux of high energy electrons, Qe, in this SNR beyond 1GeV is estimated as:

$$Qe \sim 1.5\text{x}10^{48}\ \text{erg}\ (d\ /\ 2\text{kpc})^{2}\ (10\mu\text{G}\ /\ B)^{1.6},$$

where d is the distance of SN 1006 from our solar system, and B the magnetic field in the SNR (Reynolds, 1996, , Mastiachiadis & de Jager, 1996, Ozaki, 1996, Komori, 1996). Long et al. estimated distance, d , is ranging from 1.7-3.1 kpc (Long et al. 1988). According to the preliminary data by Cangaroo group, B is estimated a little bit less than 10μG. The total output energy of electrons from SN 1006 is estimated as the order of 10^{48} erg,
The energy loss by synchrotron and inverse Compton process is proportional to the square of the electron energy ($-bE^2$), and the life time of electrons of energy E is biven by

$$T \sim 1/(bE) = 2.3.10^{5}\ \text{yr}/E(\text{TeV}),$$

where we assume $< B^2 >^{1/2} = 6.7\mu$G, taking into account of the depression of the cross-sections of the Compton effect at high energies (Van der Walt, 1991).
The average distance of R from the source traveled by an electron during time t is: $R \sim 2(Dt)^{1/2}$. Taking the case of E=1TeV, and assuming the diffusion constant is $D \sim 10^{28}(E/\text{GeV})^{\delta}\ \text{cm}^2/\text{sec}$, R is given by

$$R \sim 300\text{pc} \quad \text{for } \delta = 0.3, \qquad R \sim 1\text{kpc} \quad \text{for } \delta = 0.6.$$

Then it is clear that only nearby sources contribute to the high energy electrons.

Spectrum of Electrons from nearby Sources

We can estimate the absolute flux of electrons by assuming that the total output of electrons from each super nova is almost the same as that of SN 1006. Taking SN explosion rate is 1/30yrs in the Galaxy, and other parameters as;

Qe (>1GeV) $=1.5\text{x}10^{48}$ erg / SNR, Halo thickness: h =3kpc,
$D=1.0\text{x}10^{28}\ (E/1\text{GeV})^{\delta}\text{cm}^{2}\ /\text{sec}$ with $\delta=0.3$,
spectral index : $\gamma = 2.4$,
$b=1.3\text{x}10^{-16}\ (\text{GeV.sec})^{-1}$. for E>500GeV,
$b=1.97\text{x}10^{-16}\ (\text{GeV.sec})^{-1}$. for around 1-100GeV,

we calculate the absolute flux of electrons. The result of the calculated curve is also shown in Fig.1. We see fair agreement not only in the shape of the spectrum but also in the absolute flux.
Only few SNRs can contribute to the high energy electron flux in TeV region,, and one would expect large fluctuations of the spectrum in this energy region. (Shen, 1970, Nishimura et al., 1979, 1980, 1995 Aharonian et al., 1995, Atoyan et al., 1995).We calculate the spectrum by using data of SNRs and pulsars at a distance within 1kpc with ages less than $4\text{x}10^5$ yrs listed in the Table 1.

Tabie. 1 List of Nearby SNR and Pulsars

SNR	Pulsar	Distance	Age	Emax	Ref.
SN 185		0.95 kpc	$1.8\cdot10^{3}$ yr	136 TeV	(Strom, 1994)
S 147		0.8	$4.6\cdot10^{3}$	53	(Braun, et al., 1989)
G65.3+5.7		0.8	$2.0\cdot10^{4}$	12	(Green, 1988)
Cygnus Loop		0.77	$2.0\cdot10^{4}$	12	(Miyata, et al., 1994)
Vela	B0833-45	0.5	$2\sim3\cdot10^{4}$	8~12	(Lyne, et al., 1996)
Monogem		0.3	$8.6\ 10^{4}$	2.8	(Plucinsky, et al., 1996)
Loop 1		0.17	$2.0\cdot10^{5}$	1.2	(Eggar & Ashenbach, 1995)
Geminga	IE0630+178	0.4	$3.4\cdot10^{5}$	0.7	(Caraveo, et al., 1996)

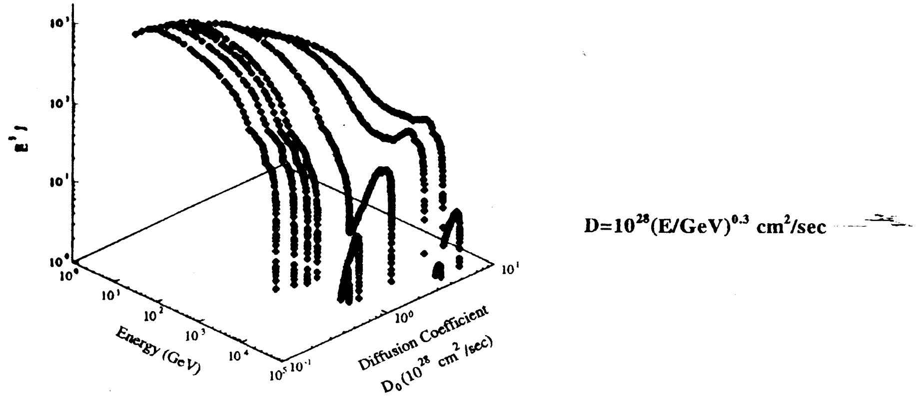


Fig. 3. Possible contribution of nearby sources to the high energy electron spectrum.
The curve is calculated by assuming that Qe (>1GeV) of each source is $1.5\text{x}10^{48}$erg.

According to the new data, the contribution of Vela becomes more dominant in TeV region and Geminga is less contributing than those we had estimated at the time of Rome Conference. Contributions from each source also depend on the propagation parameters. We illustrate the change of the spectrum with diffusion constant in Fig. 3. If we have enough statistical data in TeV region, we can judge which supernovae give major contributions. Moreover, we can estimate the probable value of the diffusion coefficient in this energy region. If the diffusion coefficient D is about $10^{29}\text{cm}^2/\text{sec}$ at around 1TeV, our observation is already at the high energy edge of the electron spectrum. Then it is possible to find the effect of the nearby sources by increasing the statistics of electron data at a few TeV regions.
Anisotropy of high energy electrons is another important subject to clarify the sources of those electrons. The anisotropy is due to the nearby sources and/or the aligned magnetic field in the Galaxy. (Earl & Lenchek, 1969 Shen & Mao, 1971). Ptsukin and Ormes reported that Vela is the most promising candidate to show a large anisotropy of 20 %. This value could be reduced by a factor of 2 to 3, by taking the recent values of age of Vela. Still we would be able to observe this anisotropy, if the diffusion constant is large enough as shown in Fig. 3 (Ptsukin & Ormes, 1995).
In this respect, the new detector of BETS seems to be the most promising to detect such anisotropy by performing a long exposure for many days or a few years.

References

Atoyan, A.M. et al., , Phys. Rev. D. **52**, No.6, 3256 (1995).
Aharonian, F.A. et al. A&A. **294,** L41. (1995).
Earl, J.A.& Lenchek, ApJ.**157**, 87 (1969).
Fowler, P.H. et al., Philos. Mag. **4**, 1030(1959).
Koyama, K., et al., Nature, **378**, 255 (1995).
Komori, Y. Private Communication (1996).
Pohl, M. A&A. **307**, 57 (1996).
Long, K.S. ApJ, 333, 749 (1988)
Mastichiadis, A. and de Jager, O.C., A&A., **311**, L5 (1996).
Migdal, A.B., Phys.Rev. **103**, 1811(1956).
Nishimura, J. et al., Proc. of 16th ICRC(Kyoto)., **1,** 478 (1979); ApJ. **238,** 394 (1980),
Proc. of 24th ICRC (Roma). **3,** 29 (1995).
Ozaki, M. Private Communication (1996).
Ptuskin V.S. and J.F. Ormes , Proc. of 24th ICRC (Roma), **3**, 56 (1995).
Reynolds, S.P., ApJ. **459**,L13 (1996).
Shen, C.S. ApJ.**162**, L181 (1970).
Shen, C.S. & C.Y. Mao, Astrophysical Letter **9**, 169, (1971).
Torii, S. et al., A&AS. 120, 665 (1996), OG7.2.4 in this issue Proc. of 25th ICRC (Durban) (1997).
Willingale, R. et al., Mon. Not. R. Astr. Soc. **278**, 749 (1996).
Van der Walt, D.J. & Steenkamp, R., Mon. Not. R. Astr, Soc. **251**, 142 (1991).
Cangaroo et al., Annual Meeting of Physical Soc. in Japan. , Nagoya, March (1997)