2P

ISSN 1340-3745

ICRR

ICRR-Report-437-98-33

Measurement of TeV Electrons on ISS / JEM

S. Torii, N. Tateyama, T. Tamura, T. Ouchi, K. Kashiwagi, K. Yoshida,
K. Hibino, T. Yamagami, Y. Saito, H. Murakami, T. Kobayashi, Y. Komori,
K. Kasahara, T. Yuda, M. Ohnishi, M. Shibata and J. Nishimura

(November, 1998)

To be presented at Space Technology & Applications International Forum (STAIF-99)

INSTITUTE FOR COSMIC RAY RESEARCH
UNIVERSITY OF TOKYO
3-2-1 Midori-cho, Tanashi, Tokyo 188-8502, Japan

Measurement of TeV Electrons on ISS/JEM

S.Torii[1a], N.Tateyama[1a], T.Tamura[1a], T.Ouchi[1a], K.Kashiwagi[1b], K.Yoshida[1b], K.Hibino[1c], T.Yamagami[2], Y.Saito[2], H.Murakami[3], T.Kobayashi[4], Y.Komori[5], K.Kasahara[6], T.Yuda[7], M.Ohnishi[7], M.Shibata[8] and J.Nishimura[9]

[1a]*Institute of Physics,* [1b]*Department of Industrial Engineering and Management and* [1c]*Institute of Computer Science, Kanagawa University, Yokohama, Kanagawa 221-8686, JAPAN*
[2] *Institute of Space and Astronautical Science, Sagamihara, Kanagawa 229-8510, JAPAN*
[3] *Department of Physics, Rikkyo University, Tokyo 171-8501, JAPAN*
[4] *Department of Physics, Aoyama-gakuin University, Tokyo 157-8672, JAPAN*
[5] *Kanagawa Prefectural College of Nursing, Yokohama, Kanagawa 241, JAPAN*
[6] *Department of System Engineering, Shibaura Institute of Technology, Omiya, Saitama 330-8570, JAPAN*
[7] *Institute for Cosmic Ray Research, University of Tokyo, Tanashi, Tokyo 188-8502, JAPAN*
[8] *Department of Physics, Yokahama National University, Yokohama, Kanagawa 240-0067, JAPAN*
[9] *Yamagata Institute of Technology, Yamagata 993, JAPAN*

Abstract. By using the JEM (Japanese Experiment Module) facility on ISS, we are planning to carry out a precise measurement of the flux and energy spectrum of cosmic-ray electrons of 10 GeV to several TeV. Since the electrons over several 100 GeV could be contributed only from the nearby sources within a distance less than 1 kpc, it is expected in the high energy region that the energy spectrum has a structural component and the distribution of the arrival directions presents anisotropy. By helping to localize and identify the nearest cosmic ray sources, these data should help to resolve the long-term puzzle. The instrument used for the observation is a kind of scintilating-fiber/lead imaging calorimeter that has been used for the balloon observations. We are developing an improved detector having a geometrical factor of 0.5 m^2sr and a higher rejection power against the background protons ($\geq 10^4$). It is expected to observe nearly 500 electrons over 1 TeV during the one-year observation.

INTRODUCTION

One major purpose of recent cosmic-ray studies is to make clear the origin, acceleration mechanism and propagation properties inside the Galaxy. Along this line many efforts have been expended to observe a precise spectrum of the various components of cosmic-rays. Electrons in cosmic-rays have unique features compared with other components, since they lose energy rapidly by synchrotron and inverse Compton processes during their propagation through the Galaxy.

Since the energy loss is proportional to the square of the energy, the life time in the Galaxy becomes much shorter for electrons beyond 100 GeV than for those cosmic-ray components for which the lifetime is mainly determined by the leakage from the Galaxy. Many theoretical and experimental efforts have been performed to study the cosmic-ray electron component since its discovery in 1961. Early studies of cosmic-ray electrons were aimed to understanding the relation between the Galactic radio waves and the confinement of cosmic-rays. Low energy electrons below 1 GeV and the cosmic nuclear component are now studied in relation to the recent gamma-ray observations as well as to study the mechanism of the charge sign dependent modulation.

These electrons in the TeV region lose their energy within a time of order of 10^5 years, and can not travel more a few hundred pc from the sources. Thus the number of sources contributing to the electrons at Earth must decrease with increasing electron energy. As a consequence we expect structure in the spectrum beyond several hundred GeV and also an anisotropy towards the nearest source of the electrons. With adequate information about the spectrum and arrival direction of electrons in the TeV region, we could identify the particular sources which contribute the observed high-energy cosmic-ray electrons. We can compare the spectral shape with those predicted by referring to the recent data of the SNRs and Pulsars. Knowing the shape of the spectrum and the nearest source, we can determine directly the diffusion coefficient of cosmic-ray particles in the nearby interstellar medium thereby tying down most critical parameter of cosmic ray propagation in the galactic magnetic fields.

The main difficulty to study such high energy electrons is the detection of those electrons. The flux is much lower compared with the abundant proton component, and we need a detector with large exposure factors and with a high rejection power against proton-induced showers. Particularly beyond 100 GeV, existing electron-spectrum data are based on very poor statistics, which prevent us from deriving clear information. We see some indications of a spectral "hump" between a few 100 GeV to 1 TeV in the existing data (Nishimura *et al.*, 1997a). However, we clearly require better statistics to judge whether this is due to the sought for structure in the spectrum.

We are proposing to put a newly developed calorimetric cosmic-ray electron-detector on ISS/JEM and to expose it for a few years to measure the spectrum ranging from 10 GeV to several TeV. The goal of this observation is to complete a high statistics measurement taking an advantage of the long exposures and high background rejection capability of the detector.

The detector is based on a scintillating-fiber/lead sampling calorimeter which is capable of fine imaging of the early part of the shower and of measuring the lateral spreads of energy distribution. As a result of those measurement, a high statistics measurement would be made of 10 GeV to several TeV electrons. The scientific goal of these measurements in the identification of the few nearest cosmic-ray sources, the diffusion coefficient of cosmic rays in the local interstellar medium and accurate prediction of the inverse Compton contribution to the diffuse gamma-ray emissivity in the range above 10 GeV.

ASTROPHYSICAL SIGNIFICANCE OF HIGH ENERGY ELECTRONS

We now briefly summarize the astrophysical significance of high energy electrons to be observed by the facility of JEM/ISS (Nishimura *et al.*, 1997b). The energy loss by synchrotron and inverse Compton process is proportional to the square of the electron energy, and the life time, T, of electrons of energy E is

$$T = 2.3 \times 10^5 yr./E(TeV) = 1/bE,$$

where we assume $\langle B^2 \rangle = 6.7\mu G$, taking into account the depression of the cross-sections of the Compton effect at high energies (Van der Walt, 1991).

The average distance of R traveled by an electron during time t is obtained as $R \sim (4\bar{D}t)^{1/2}$. $\bar{D}$ is time average of diffusion constant of D for particles of energy E, and can be expressed as

$$\bar{D} = D_o(E/GeV)^\delta(1 - (1 - bEt)^{1-\delta}/\{(1-\delta)bEt\}.$$

Taking the case of E=500GeV, and assuming $D_o \sim 10^{28}(E/GeV)^\delta cm^2$ /sec, R is given by

$$R \sim 500pc \text{ for } \delta = 0.3\ ,\ R \sim 1.5kpc \text{ for } \delta = 0.6.$$

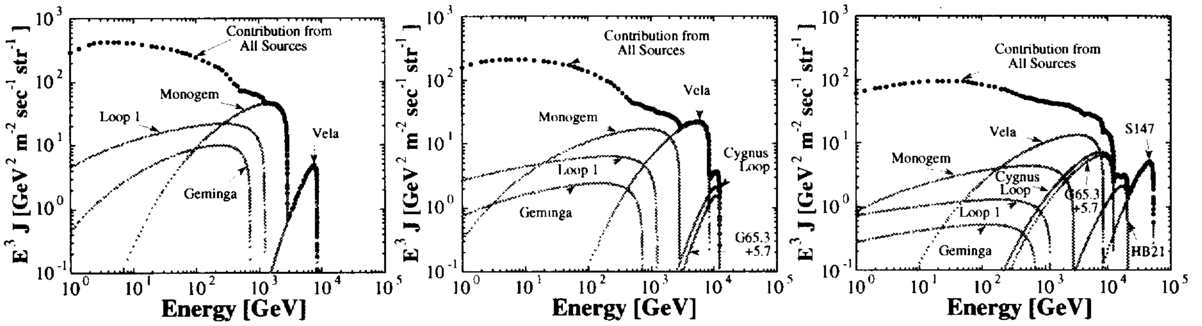
It is clear from these values that only nearby sources contribute to the high energy electrons in the Solar system.

Energy Spectrum of Electrons from Nearby Sources

Assuming electrons are accelerated at the SNRs and the Pulsars, we can estimate the possible contributions of those nearby sources (Shen, 1960 Nishimura *et al.*, 1979 Aharanian *et al.*, 1995). The SNRs and pulsars at a distance within 1kpc with ages less than $\sim 10^5$ years are tabulated in Table 1. Loop 1 was once supposed to be the strongest candidate contributing to TeV region. Its estimated age changed, however, from $\sim 10^4$

TABLE 1. List of SNRs and Pulsars as Candidates of Nearby Electrons Sources

SNR	**Pulsar**	**Distance**	**Age**	$\mathbf{E}_{max}$	**Ref.**
SN 185		0.95 kpc	1.8×10^3 yr	130 TeV	(Strom,1994)
S 147		0.8	4.6×10^3	50	(Braun *et al.*,1989)
G65.3+5.7		0.8	2.0×10^4	12	(Green 1988)
Cygnus Loop		0.77	2.0×10^4	12	(Miyata *et al.*,1994)
Vela	B0833-45	0.5	$2 \sim 3 \times 10^4$	$8 \sim 12$	(Lyne,1996)
Monogem		0.3	1.0×10^5	2.3	(Pulcinsky *et al.*,1996)
Loop 1		0.17	2.0×10^5	1.2	(Eggar & Ashenbach,1995)
Geminga	IE0630-178	0.3	3.4×10^5	0.7	(Caraveo *et al.*,1996)



(a) $D = 6 \times 10^{27} (E/1\text{GeV})^{1/3}$ (b) $D = 2 \times 10^{28} (E/1\text{GeV})^{1/3}$ (c) $D = 6 \times 10^{28} (E/1\text{GeV})^{1/3}$

FIGURE 1. Possible contribution of nearby sources to the high energy electron spectrum and the dependence on the diffusion constants. Contributions from each source and the total sum including these from other sources are presented by dotted lines.

to 10^5 years, and the contribution is much reduced. Furthermore, there are some arguments Loop 1 could be a star burst near the Galactic Center (Sofue, 1994). If this is the case, we can not expect contributions from Loop 1 for high energy electrons.

We illustrate, in Fig.1, the degree of contribution of the nearby SNRs referring to the data given in Table 1. Only 3 of SNRs (Loopl, Monogem and Geminga) contribute to the electron flux around $1 \sim 2$ TeV. As a consequence, one would expect structure representing the nearby sources to be present in this energy region. The low statistics of the present data prevents us from telling if the spectrum is a power low or not in this region. Clearly, more precise measurements with higher statistical precision are required. Contributions from each source also depend on the propagation parameters. We illustrate, also in Fig.1, how the spectrum changes with the assumed diffusion coefficient.

Given enough data beyond several hundred GeV, we can judge which supernova gives the major contribution to the flux. Moreover, we can determine the value of the diffusion coefficient in this energy region. If the diffusion coefficient D is about 10^{29} cm^2 /sec around at TeV region, the emulsion observation (Nishimura *et al.*, 1997a) is already at the highest energy end of the electron spectrum.

Relating to the SNR origin of cosmic-rays, recent observations of X-rays reveal the evidence of acceleration of electrons of a single power spectrum up to 100 TeV in the shock of SN1006 (Koyama *et al.*, 1995). The total amount of energy of electrons accelerated in SN1006 is estimated as $\sim 10^{48}$ erg (Reynolds, 1996), which is enough to explain the absolute flux of observed electrons.

Anisotropy of High Energy Electrons

Anisotropy of high energy electrons has been proposed as due to (Earl and Lenchek, 1969 Shen and Mao, 1971)

- Magnetic field aligned along the Galactic arm
- Diffusion from nearby source

As indicated by Ptsukin and Ormes (1995), and other papers, the anisotropy from a single source is given by

$$\Delta = \frac{3D}{c}\frac{\nabla N}{N} = \frac{3}{2}\frac{R}{ct}$$

They indicated that Vela is the most promising candidate to show a large anisotropy of 20 % at around 10 TeV. One may, however, expect to observe possible anisotropy even in several hundred GeV region due to other unexpected sources or due to the aligned magnetic-field, which have never been observed in the past any kind of observations.

ELECTRON MEASUREMENT

The present data show that the flux of primary electrons is estimated to be about $3/(m^2 \cdot str \cdot day)$ beyond 1 TeV. The ratio of protons to electrons increases progressively with energy and becomes 10^3 at around 1 TeV. We need, therefore, a detector of large geometrical factor with rejection power of at least 10^4 for observing the electrons in TeV region.

The highest energy observation with an electronic detector up to now was carried out by the Chicago group (Tang, 1984). Their detector is one of the most advanced, consisting of a transition radiation and a time of flight detector with a shower detector. Transition radiation detectors discriminate electrons against protons by responding to the difference in Lorentz factor. However, the observation was limited to a few 100 GeV. The pioneering work using emulsions to detect high energy electrons was first carried out by the Tata group (Daniel and Stephens, 1965). They used emulsion stacks and detected electrons up to several hundred GeV. The merit of the emulsion detector is two fold: 1) the starting point of the shower can be inspected to identify clearly electron-induced showers from those of hadronic origin and 2) the detector has a large acceptance angle.

By developing their work, the emulsion chamber observations have now extended the observed spectrum up to a few TeV (Nishimura it et al., 1997a). Despite of its several merits, emulsion chambers can not be used for long duration exposure because of accumulation of background tracks and flooding by lower energy electrons below 100 GeV. Also emulsions must be scanned by hand procedure that imposes a practical limit to the statistics one can obtain. Moreover, it can not be used to observe the anisotropy of the electrons , since it has no timing information.

To resolve these problems, a new imaging detector has been developed with scintillating fibers. In this type of detector, some difficulties in the past electronic detectors are removed while preserving the superior qualities of both electronic detectors and emulsion chambers. Namely, we can observe details of shower starting points and shower profiles developing in a detector with a timing capability. We have already developed such a detector called BETS (Balloon Borne Electron Telescope with Scintillating Fibers). The BETS detector has been proven to be capable of observing electrons of 10 GeV to 100 GeV in a balloon flight (Torii *et al.*,1996 Torii *et al.* 1997). Further, its performance has been validated by the accelerator beam tests at CERN-SPS (Tamura *et al.*, 1998).

We are developing this type of scintillating fiber detector on board the ISS/JEM to measure precisely the energy spectrum and anisotropy of high-energy electrons. In order to add the additional proton rejection power required at higher energy, the structure of detector has been studied by simulations on material thickness and segmentation for imaging. These are enable us to improve rejection power against the background protons to be larger than 10^4, adequate for the observations.

BASIC DESIGN OF PAYLOAD AND ITS PERFORMANCE

For observing TeV electrons, it is necessary to achieve an exposure over a few 100 day·m^2·sr to the cosmic radiation in order to explore questions on the propagation and source distribution of electrons in the Galaxy. This amount of exposure is nearly two-order of magnitude larger than than the total observation by all past emulsion chambers. Such a large exposure can be achieved only by an observation for few years and a large geometrical factor of 0.5 m^2· sr.

Detector Overview

To meet the requirements of both large geometrical factor and high rejection capability against hadrons, the BETS detector has been successfully developed by us during the last five years (Murakami *et al.*, 1998). The BETS is using a unique technique of imaging shower profiles for discrimination of electrons against the proton background. This technique is valid in the energy region above 10 GeV. The imaging of detailed shower profiles is achieved using about 10,000 scintillating fibers interleaved lead plates of a total thickness of $\sim$ 7 r.l.

A planned detector of TeV electrons used at JEM, of which schematic view is presented in Fig. 2, will have the following composition. The SciFi/Lead imaging calorimeter with an area of 50 × 50 cm^2 consisting of 23,000 scintillating fibers and 13 r.l thickness of lead. Each fiber plane is made of 500 fibers with a 1 mm square cross section for each. The fiber is spliced to an optical (clear) fiber, which is used as light guide, at the edge of detector part in order to be free from the noises. Each of 50 cm clear fiber outputs are split to into tabs which are stacked and bonded together. Four sets of the fiber outputs are routed to each of an image-intensified CCD camera for read out. The CCD camera has an input window with a diameter of 10 cm and has a "shutter" function which is operated by a gate signal from the trigger system. Two cameras are used for each direction; four cameras in total. For calibration, LED lights are irradiated to the camera through clear fibers. The performance and general characteristics of the payload is summarized in Table 2.

Expected flux

Table 3 presents the expected flux by one-year observation with a detector of 0.5 m^2· sr by assuming that the differential energy spectrum can be extrapolated from lower energies with a power law of -3.3.

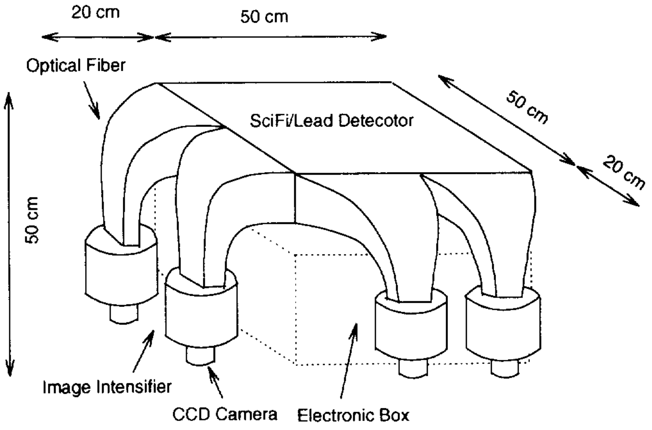


FIGURE 2. Schematic view of the electron telescope for the JEM experiment. The telescope consists of 13 r.l. thick lead and 23,000 scintillating fibers (1mm square cross section). Four image-intensified CCD cameras are used for the read-out. The detector has square area of 50cm× 50cm and the thickness is about 15cm.

TABLE 2. Instrument Performance

Energy Range (GeV)	10 ~ several 1,000
Geometrical Factor (m^2 sr)	0.5
Proton/Electron Discrimination	$\geq 10^4$
Energy Resolution (%)	≤ 15
Angular Resolution (degree)	0.7 ~ 1.2
Weight (kg)	~ 300
Power Consumption (W)	≤ 100

TABLE 3. Expected Number of Electrons in the One-year Observation

Energy	> 10 GeV	> 100 GeV	> 1,000 GeV	> 3,000 GeV
Electron Number	2.0×10^7	1.0×10^5	5.2×10^2	4.0×10^1
Electron/Proton	8.5×10^{-3}	2.4×10^{-3}	6.8×10^{-4}	3.6×10^{-4}

SUMMARY

By extension of the electron observation up to the TeV region, it is strongly predicted that effects of the local sources would be observed . The energy spectrum over several 100 GeV is thought to have a humped structure in the shape and has the cut-off above several TeV. The anisotropy of arrival directions is accordingly expected in the TeV region. These observations must bring conclusion results on the cosmic ray acceleration mechanism in super nova and the diffusion mechanism in the galaxy. In order to perform the crucial observation, we are developing a new type detector based on the BETS instrument for balloons. We propose to launch it in space with JEM in the forthcoming international space station. The expected flux of electrons above 1 TeV for the one-year observation is about 500.

ACKNOWLEDGMENTS

This work is supported by Grant (Phase Ia) from the Japan Space Forum and Grants-in-Aid for International Scientific Research (Field Research) from the Ministry of Education, Science, Sports and Culture in Japan.

REFERENCES

Aharonian, F.A. *et al.* *Astronomy and Astrophysics* **294**, L41 (1995)

Daniel,R.R. and Stephens S.A. Phys. Rev. Letters **15**, 769 (1965)

Earl, J.A. and Lenchek *Ap. J.* **157**, 87 (1969)

Koyama, K. *et al.* Nature **378**, L255 (1995)

Murakami H. *et al.*, *Adv. Sp. Res.* **21**, 1029 (1998)

Nishimura, J. *et al.* *Proc. of the 16 th International Cosmic Ray Conference* **1**, 478 (1979)

Nishimura J. *et al.*, *Ap. J.* **238**, 394 (1980)

Nishimura J. *et al.* *Proc. of the 25 th International Cosmic Ray Conference* **4**, 223 (1997a)

Nishimura J. *et al.* *Adv. Sp. Res.* **19**, 767 (1997b)

Ptuskin V.S. and Ormes J.F *Proc. of the 24 th International Cosmic Ray Conference* **3**, 56 (1995)

Renolds, S.P. *Ap. J.* **450**, L13 (1996)

Shen, C.S. *Ap. J.* **181**, L162 (1960)

Shen, C.S. and Mao. C.Y. *Astrophysical Letter* **9**, 169 (1971)

Sofue,Y. *Ap. J.* **431**, L91 (1994)

Tamura T. *et al.* *COSPAR98, to be published in Adc. Sp. Res.(1998)*

Tang K.K., Ap. J. **278**, *881 (1984)*

*Torii S. et al., Proc. of SPIE, Gamma-Ray and Cosmic-Ray Detectors,Techniques, and Missions,***2806***,145 (1996).*

Torii S. et al., Proc. of the 25 th International Cosmic Ray Conference **3**, *117 (1997)*

Van der Walt D.J. Mon. Not. R. Astr. Soc. **251**, *143 (1991)*