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MEASUREMENT OF HIGH-ENERGY COSMIC-RAY ELECTRONS WITH A POLAR PATROL BALLOON

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Abstract: One of the major purpose of recent cosmic-ray studies is to know the origin, acceleration mechanism and propagation properties inside the Galaxy. Along this line many efforts have been spent to observe a precise spectrum of the electron component of cosmic-rays. The main difficulty to study high-energy electrons is the detection of these electrons. The flux is much lower than the abundant proton component, and we need an observation of long duration and a detector with a high rejection power against the background protons.

We propose to carry a newly developed scintillating-fiber detector on the Polar Patrol Balloon (PPB) and to expose it for 30 days. The goal of this observation is to determine a definite electron energy-spectrum ranging from 10 GeV to TeV region based on a high statistical accuracy with a long exposure by the PPB. In the result, we can expect to obtain direct evidence for the origin of high-energy electrons and a precise knowledge of their propagation in the Galaxy including solar modulation effects on the electron flux.

1. Introduction

Many theoretical and experimental efforts have been performed to study the cosmic-ray electrons since its discovery in 1961. Early studies of cosmic-ray electrons were to find the relation between the Galactic radio waves and the confinement time of cosmic-rays. Low energy electrons below 1 GeV are now studied also in relation to the recent gamma-ray observations as well as to the mechanism of the charge dependent modulation.

Electrons in cosmic-rays have unique features compared with other components, since they lose energy rapidly through synchrotron and inverse Compton processes during their travel in the Galaxy. The amount of energy loss rate is proportional to the square of the energy. Then, the life time in the Galaxy becomes much shorter beyond 100 GeV than that of other cosmic-ray components which is mainly determined by the leakage from the Galaxy.

The number of electron sources decreases progressively with the increase of electron energy. As a result, we might expect a large fluctuation in the energy spectrum beyond several hundred GeV and also an anisotropy of the arrival directions of electrons. We could, therefore, identify the particular sources which contribute to the observed high-energy cosmic-ray electrons. We can discuss the spectral shape referring to the recent data of the SNRs and Pulsars tabulated in Table 1. The spectral shape depends also on the diffusion parameters, and the observations of high energy electrons are important to resolve the diffusion models as presented in Fig. 1 (KOBAYASHI *et al.*, 1998). For the electrons around 10 GeV, both of solar modulations and diffusive reacceleration in the Galaxy have considerable effects on the flux (KOMORI *et al.*, 1998; KOMORI, private communication, 1998).

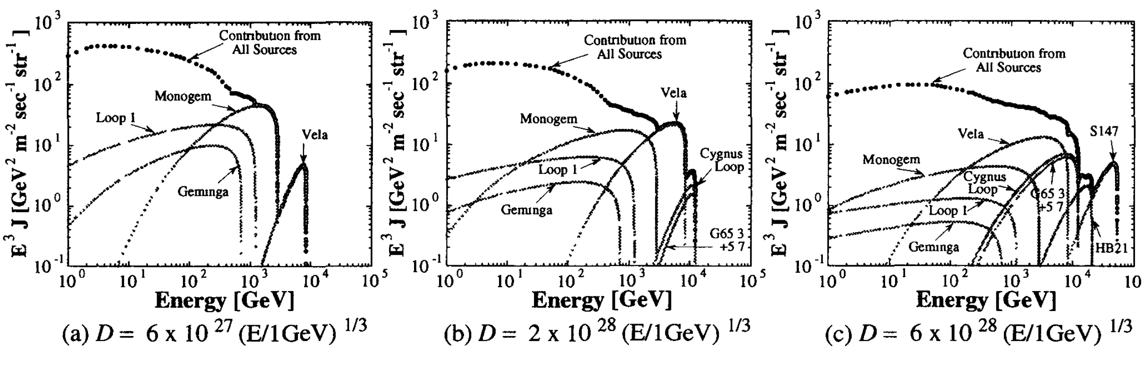
It has been recognized that long duration ballooning is very effective to measure cosmic rays, and many opportunities are recently announced for various observations by NASA. The Polar Patrol Balloon (PPB) was proposed and successfully carried out in Japan for low-energy cosmic rays (EJIRI *et al.*, 1993). The PPB is unique for the long-duration ballooning to collect high-statistics data which has never been obtained in usual ballooning. Especially, the electron component in cosmic-rays is very difficult to observe in higher energy region since the flux is considerably smaller comparing to the proton component.

It is proposed that a newly developed scintillating-fiber detector will be borne on the PPB and exposed for 30 days. By this observation, we can increase the statistics of

Table 1. List of SNRs and pulsars as candidates of nearby electrons sources.*

SNR	Pulsar	Distance	Age	E_{max}	Reference
SN 185		0.95 kpc	1.8×10^3 yr	130 TeV	(STORM, 1994)
S 147		0.8	4.6×10^3	50	(BRAUN *et al.*, 1989)
G 65.3+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	B 0833-45	0.5	$2\sim3\times10^4$	$8\sim12$	(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 and ASHENBACH, 1995)
Geminga	IE 0630-178	0.3	3.4×10^5	0.7	(CARAVEO *et al.*, 1996)

*This is quoted from KOBAYASHI *et al.* (1998). The references in table are presented therein.



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

Fig. 1. Possible contribution from nearby sources to the high energy electron spectrum and the dependence on the diffusion constants (KOBAYASHI et al., 1998). Contributions from each source and the total sum including those from other sources are presented by dotted lines.

electron number by 100 times comparing with the current observation in Sanriku. Then, it is expected to detect the possible effect of the contribution of near-by sources and judge the most appropriate parameters in the diffusion model. The precise spectrum of electrons also enable us to analyze the details of solar modulation effects and reacceleration mechanism in the Galaxy.

2. Method of Electron Measurement

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 carried out by the Japan-US collaboration (Nishimura *et al.*, 1980). They used emulsion chamber and detected electrons up to 1 TeV. The merit of the emulsion chamber is two fold: 1) the starting point of the shower can be inspected to identify clearly electron-induced showers from the showers by nuclear interactions and 2) the detector has a large geometric factor.

The emulsion chamber observations have now extended the observed spectrum up to a few TeV (Nishimura *et al.*, 1997). Despite of its several merits, emulsion chambers cannot be used for long duration exposure, because of accumulating background tracks and flooding by lower energy electrons below 100 GeV. Also emulsions must be scanned by hand that gives a practical limit to the statistical counting. Moreover, it cannot be used for observing 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 previous electronic detectors are removed while preserving the superior qualities of both electronic detectors and emulsion chambers. Namely, we can observe details of shower starting instants 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 several 100 GeV in a balloon flight (Torii *et al.*, 1996, 1998; Murakami *et al.*, 1998). Further, its performance has been validated by the accelerator beam tests at CERN-SPS (Tamura *et al.*, 1998).

We are developing a detector improving the BETS instrument for the PPB to measure precisely the energy spectrum and anisotropy of high-energy electrons. In this development, various improvements of the instrument will be carried out in reducing the weight and in saving the electric power to satisfy the requirements from the PPB. A new trigger system will, also, be developed for simultaneous observation gamma-rays in GeV region. Moreover, a new telemetry system using a satellite link technology will be used in the observation.

3. Detector for the PPB Observation and Expected Results

Scintillating fiber (SciFi) is efficient in detecting tracks of charged particles, and has been developed in accelerator experiments. We adopt it as a sensitive layer of imaging sampling calorimeter. A planned detector for the PPB observation, of which schematic side-view is presented in Fig. 2, has the similar composition of SciFi and lead with the BETS as following. A SciFi, *Kuraray SCSF77,* has one millimeter diameter and involves a poly-styrene core ($n=1.59$) surrounded by a poly-methylmetacrylate (PMMA) clad ($n=1.49$). A SciFi belt is composed of 280 fibers (1 mm each) in one millimeter pitch. At each depth, two belts are crossed at the right angle (*i.e., x* and *y* directions).

The fiber is spliced to an optical (clear) fiber, which is used as a light guide, at the edge of detector part in order to be free from the noises. Each of clear fiber outputs are split into tabs which are stacked and bonded together. Two 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 operated by a gate signal from the trigger system. Two cameras are used for each direction. For calibration, LED lights are irradiated to the camera through clear fibers. The system will have an electronics system, of which block diagram is presented in Fig. 3.

Expected performance and general characteristics of the detector are summarized in Table 2. Table 3 shows the expected flux for 30-days observation with a detector of 500 $cm^2 \cdot sr$ by assuming that the differential energy spectrum can be extrapolated from lower energies with a power law of -3.3. In the table, the estimated ratios of the background protons to electrons are also listed in each energy region.

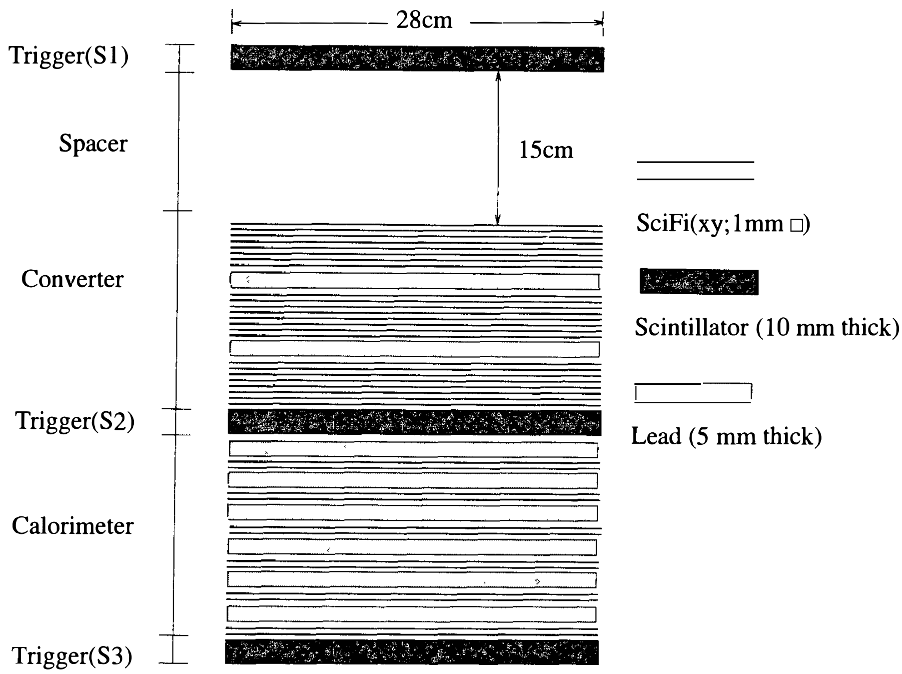


Fig. 2. Schematic side-view of the detector.

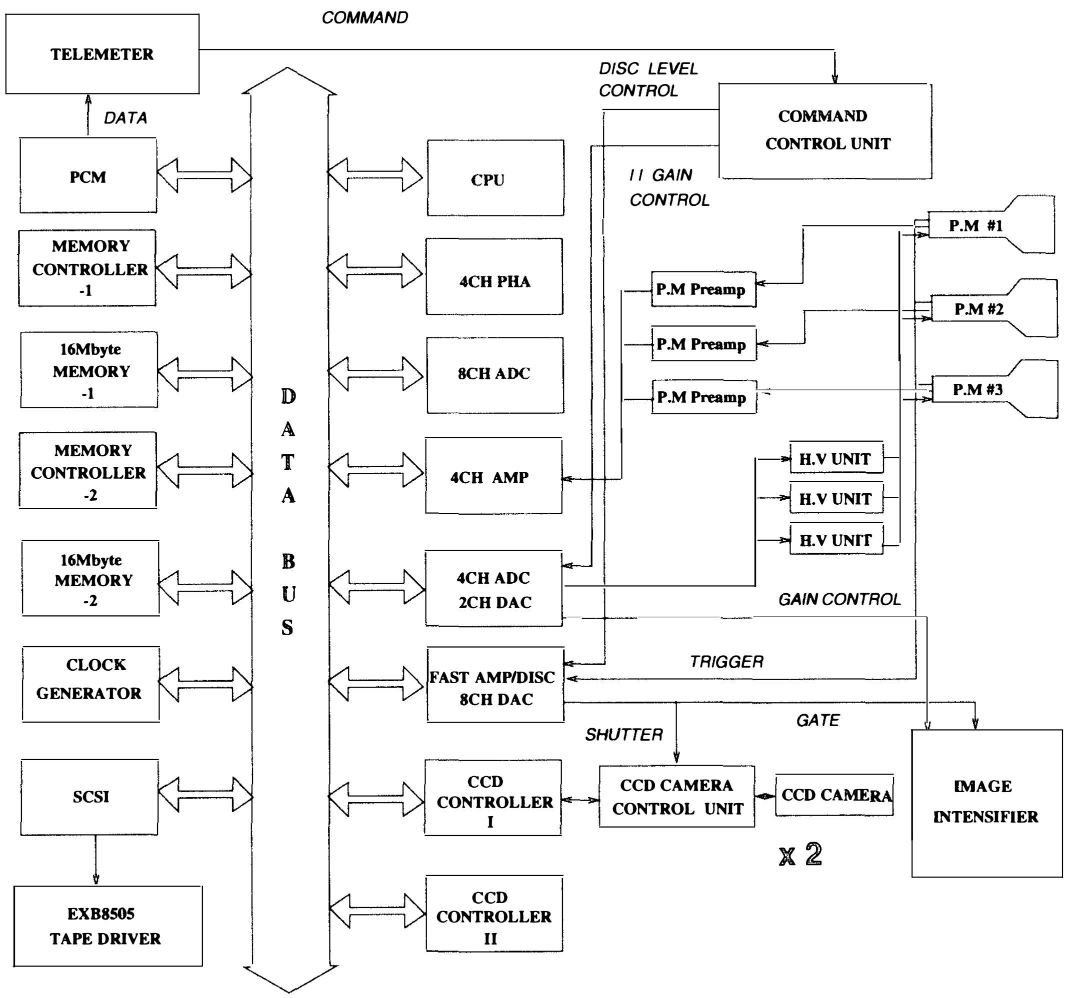


Fig. 3. Block diagram of the electronics system of the BETS detector. Similar system will be used in the instrument for PPB.

Table 2. Instrument performance.

Parameter (unit)	Expected or planned performance
Energy range (GeV)	10～1000
Geometrical factor (cm^2 sr)	500
Proton/electron discrimination	～10^4
Energy resolution (%)	～15
Angular resolution (degree)	0.7～1.2
Weight (kg)	～200
Power consumption (W)	≤50
Observation altitude (km)	≥35
Telemetry speed (kbits/s)	2.4

Table 3. Expected observed number of electrons in the 30-days PPB observation.

Energy	>10 GeV	>100 GeV	>1000 GeV
Electron number	1.7×10^5	8.4×10^2	4
Background proton ratio to electron	120	410	1500

4. Discussion and Summary

It is expected to extend the electron observation up to the TeV region using the PPB. Then, a histrical question of cosmic-ray origin will be possibly resolved through localizing and identifing the nearest cosmic-ray sources. These observations must also indicate a precise conclusion 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. We propose to launch it with the PPB in the forthcoming expedition to the Antarctica by the National Institute of Polar Research (NIPR).

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References

EJIRI, M., KADOKURA, A., HIRASAWA, T., SATO, N., FUJII R. *et al.* (1993): Polar Patrol Balloon Experiment in Antarctica. Adv. Space Res., **13**, 127.

KOBAYASHI, T., NISHIMURA, J., KOMORI, K., TAIRA, T. and YOSHIDA, K. (1998): Contribution of nearby sources to the high energy electron spectrum. Uchukagaku Kenkyusho Hôkoku (ISAS Report), **37**, 76–94 (in Japanese with English abstract).

KOMORI, K., NISHIMURA, J., KOBAYASHI, T., TORII, S. and YAMAGAMI, T. (1998): Diffusive reacceleration of cosmic ray electrons in the Galaxy. Uchukagaku Kenkyusho Hôkoku (ISAS Report), **37**, 95–111 (in Japanese with English abstract).

MURAKAMI, H., NISHIMURA, J., TORII, S., KASAHARA, K., TAMURA, T. *et al.* (1998): A balloon-borne electron telescope with scintillating fibers. Adv. Space Res., **21**, 1029–1032.

NISHIMURA, J., FUJII, M., TAIRA, T., AIZU, E., HIRAIWA, H. *et al.* (1980): Emulsion chamber observation of primary cosmic-ray electrons in the energy range 30–1000 GeV. Astrophys. J., **238**, 394–409.

NISHIMURA, J., KOBAYASHI, T., KOMORI Y. and YOSHIDA K. (1997): Observations of high energy primary electrons and their astrophysical significance. Adv. Space Res., **19**, 767–770.

TAMURA, T., TORII, S., YOSHIDA, K., YAMAGAMI,T., MURAKAMI H. *et al.* (1998): Performance of the BETS detector for cosmic ray electrons. Adv. Space Res. (in press).

TANG, K.K. (1984): The energy spectrum of electrons and cosmic-ray confinement: a new measurement and its interpretation. Astrophys. J., **278**, 881–893.

TORII, S., NISHIMURA, J., KASAHARA, K., TATEYAMA, N., TAMURA, T., YAMAGAMI, T., OHTA, S., NAMIKI, M., KOBAYASHI, T., MURAKAMI, H. and YUDA, T. (1996): Balloon-borne electron telescope with scintillating fibers. Proc. Soc. Photo-Opt. Instrum. Eng., **2806**, 145–154.

TORII, S., TATEYAMA, N., TAMURA, T., YOSHIDA, K., YAMAGAMI,T., MURAKAMI H., KOBAYASHI T., YUDA T. and NISHIMURA J. (1998): A Pb-SciFi imaging calorimeter for high energy cosmic electrons. AIP Conf. Proc. (SCIFI97), **450**, 578–585.

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