Japan-Australia Cooperative Observation of North-South Asymmetry in Intensity Variation of High Energy Cosmic Rays ($\lesssim 10^{12}$eV)

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(Received December 18, 1992)

Abstract

Japan-Australia cooperative observation between Shinshu University and University of Tasmania commenced in December 1991 to measure the north-south (N-S) asymmetry in the intensity variation of high energy cosmic rays ($\lesssim 10^{12}$eV). In the project an emphasis is particularly laid on the measurement of the N-S asymmetric sidereal anisotropy to reveal three-dimensional nature of anisotropies of galactic origin. This is the first bi-hemisphere comparative underground observation, and was motivated on the basis of recent data obtained by multi-directional telescopes at Matsushiro (220 m.w.e. depth underground) of Shinshu University and at Sakashita (80 m.w.e. depth underground) of Nagoya University. The data show that at rigidities ~400 GV to ~1 TV, the observed diurnal amplitudes appear to increase as the detector's latitude of viewing moves southward, suggesting its N-S asymmetric nature of the sidereal time variation. The evidence is, however, limited only in the northern hemisphere, and has no positive confirmation yet in the southern hemisphere. To get further information about the N-S asymmetric anisotropy, Japanese group proposed the bi-hemisphere comparative observation with similar equipments and at similar rigidities. Two cosmic ray groups of Shinshu University and University of Tasmania, Australia agreed with each other, both financially supported, to push a joint project and open a pair underground stations ; one at Matsushiro (in operation since 1984), Japan and the other at Liapootah (newly constructed) in Tasmania, Australia. The Liapootah

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underground station (42°20′S, 146°28′E) is situated in a central part of Tasmania Island, and has such characteristics as ; located at almost conjugate position to Matsushiro (36°32′ N, 138°01′ E), at almost comparable underground depth (approximately 154 m. w.e.) to Matsushiro (220 m.w.e. depth), and with almost similar rigidities of primaries (~500 GV-1 TV). The muon telescope used at Liapootah is quite similar to that at Matsushiro ; of plastic scintillators viewed with double photomultipliers and of multi-directional. Nearly equal counting-rates of muons are obtained at two stations ; $\sim 2 \cdot 10^4$/hr for the vertical telescope, and $5\text{-}7 \cdot 10^3$/hr for the inclined telescope (towards north-, south-, east- and west-direction). In the present paper, we describe the underground site and the muon telescope at Liapootah in some details, with a comparsion of those at Matsushiro. All the electronics system including data sending are controlled by means of the micro-computer system via public telephone lines from both universities at Hobart and Matsumoto.

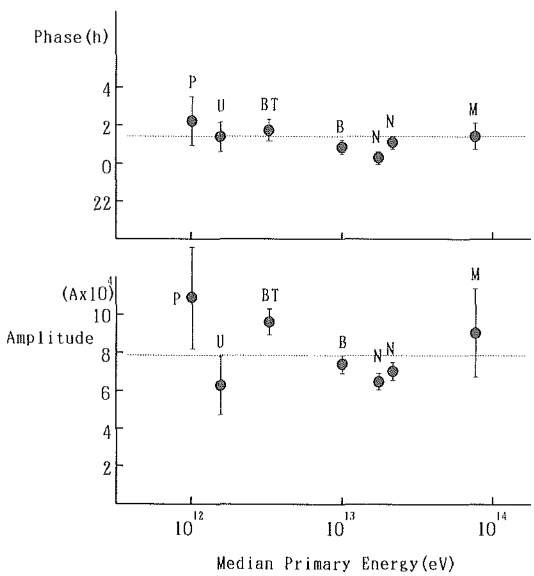


Fig. 1. Dependence of the observed sidereal 1-st harmonics on median primary energy ; the amplitude (projected on the equatorial plane) and the phase (time of maximum). Data are taken from various underground (UG) and air-shower (AS) measurements ; P-Poatina (UG), U-Utah (UG), BT-Baxan (UG), B-Baxan (AS), N-Mt. Norikura (AS), M-Musala (AS) (cited from Andreyev et al., 1987). The lines are tentatively drawn by us, showing its invariant nature.

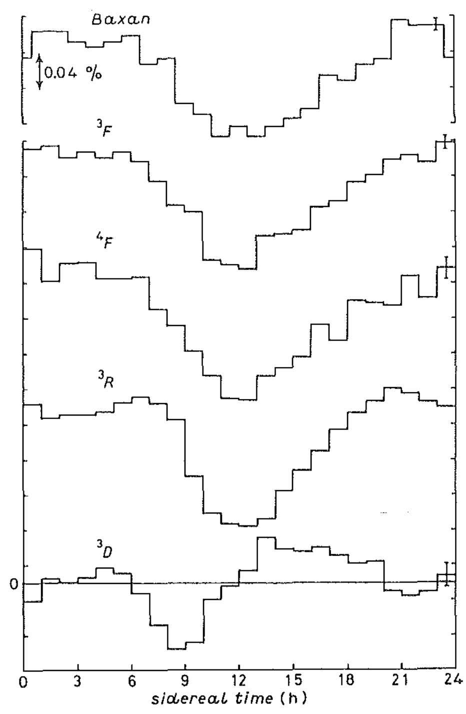
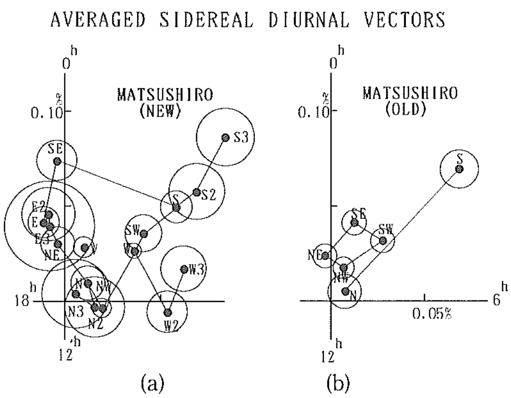


Fig. 2. Hourly behaviour of sidereal daily intensity of air-showers at Mt. Norikura and Baxan (cited from Nagashima et al., 1989)).

Introduction

The measurements of sidereal anisotropies of galactic cosmic rays have long been performed by a great many research workers since the discovery of cosmic radiations to obtain information about the origin and propagation of cosmic rays in space. The observations have been carried out in a wide range of rigidity, mostly at the underground (median primaries of 10^{11}-10^{12}V in rigidity) and recently by means of air-shower mesurements ($\sim 10^{13}$V) (e.g., Nagashima and Mori, 1976 ; Kiraly et al., 1979 ;



(a) averaged over 5-year period (1984-1989) for 17 directional telesopes at (new) Matsushiro and (b) averaged over eight-year period (1980-1989) for 6 directional telescopes at (old) Matsushiro. In the figure the symbols represent directional telescopes. To show a relationship among data of directional telescopes each vector is connected with solid line. The error circles are derived from dispersion of yearly mean.

Fig. 3. Observed sidereal diurnal vectors at two (new and old) Matsushiro underground stations ;

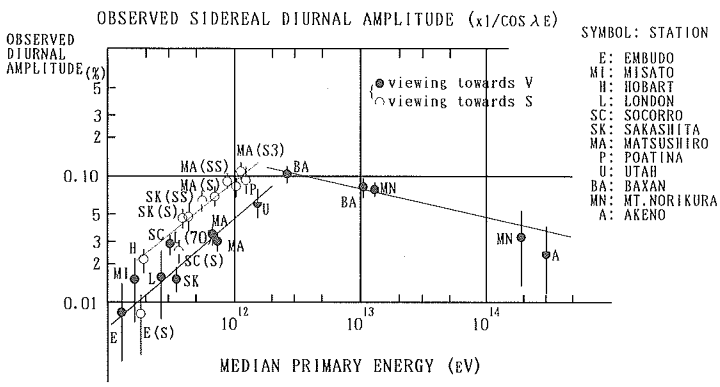
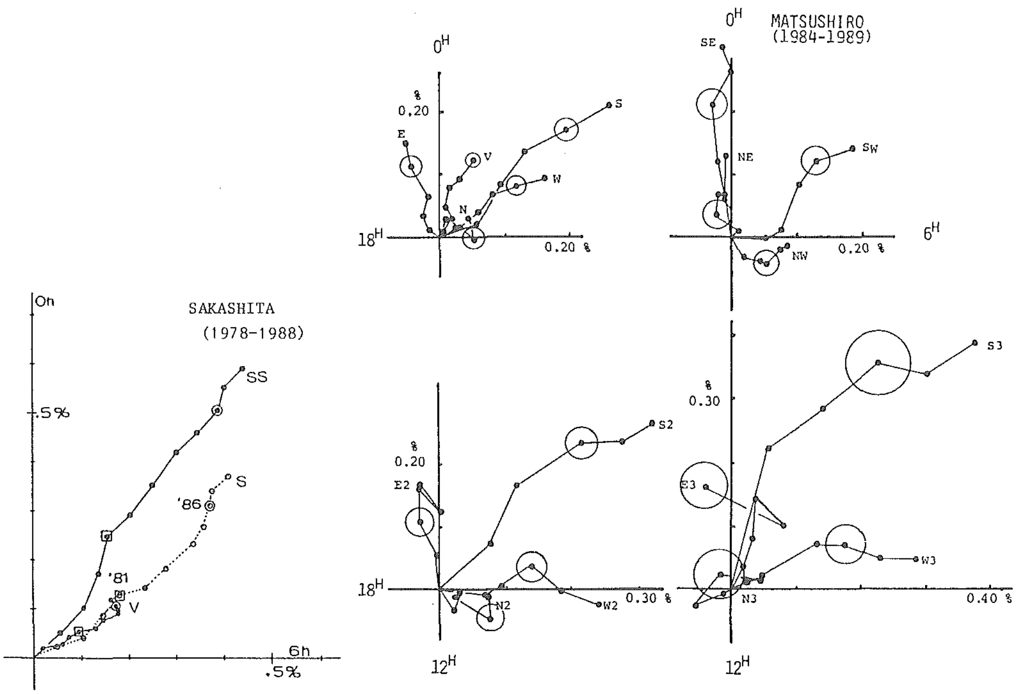


Fig. 4. Observed sidereal diurnal amplitudes for two groups (projected on the equatorial plane) plotted as functions of median primary rigidities ; data of S- telescopes are plotted with open circles and dotted line, and data of V-telescopes are with black circles and solid line. Data are taken from various underground and air-shower measurements as indicated with symbols in the figure. Also symbols in the parentheses (S, SS, and S3) of S-group represent the inclined S-telescopes, and 70 denotes the London inclined telescope by 70° to the vertical. Solid line on the air-shower data is cited from Nagashima et al. (1989).

Jacklyn, 1986 ; references therein). Much data are accumulated and the related pictures of anisotropies are so far presented. Among them the following summary may be referred to here that the observed anisotropies in the rigidity region 10^{12}-10^{14}V appear to be rather invariant in amplitude and phase (i.e., right ascension of the maximum) as shown in Figure 1 (cited from Andreyev et al., 1987 ; Gombosi et al., 1975 ; Alexeenko et al., 1981 ; Humble and Fenton, 1984 ; Cutler et al., 1981), although the declination is not certain. Based on this, it has been interpreted for some time that the anisotropic flows would be due to diffusive (Kiraly and Kota, 1979) or advective allowig the Compton-Getting effect (Axford et al., 1991). An improved picture was given by Nagoya group, inferred from their own air-shower data (~100 TeV) by means of



(a) (b)

Fig. 5. Sum harmonic dial of the observed sidereal diurnal vectors ; (a) for V-, S-, and SS-telescopes at Sakashita, (1978-1988 ; cited from Ueno et al., 1990), and (b) for 17 directional telescopes at Matsushiro, where the errors are derived from counting-rates (1984-1989 ; cited from Mori et al., 1989).

directional and long-term measurements (for about 20 years) at Mt. Norikura (Nagashima et al., 1989). With a detailed examination of the observed hourly histogram shown in Figure 2 (cited from Nagashima et al., 1989) and its harmonic analysis of arrival direction they proposed that the anisotropy may be due to deficiency

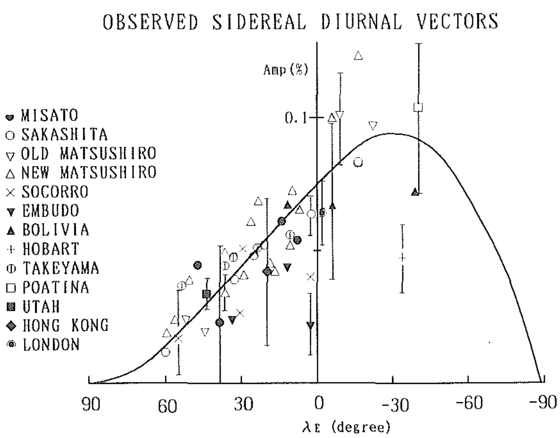


Fig. 6. Observed sidereal diurnal amplitudes at various underground stations listed in the figure, plotted as functions of effective latitudes of viewings, where the error bars are taken from their originals. In the figure a calculated curve is also fitted, which was evaluated by assuming two terms of anisotropy; N-S symmetric and N-S asymmetric type in free space. In the calculation both spectra are assumed to be flat in rigidity with $P_L = 200$ GV.

in a particular direction rather than to a simple anisotropy (Andreyev et al., 1987; Bergamasco et al., 1992). It is noted here that the above proposed (axis-symmetric) distribution may produce the diurnal term of north-south (N-S) asymmetric as well, and this should be observed at the conjugate station in the southern hemisphere with the same amplitude in the phase of 12 hr apart from that in the northern hemisphere. For determining a reliable structure of three-dimensional anisotropy enough information in the southern hemisphere is not available at the present moment (Jacklyn, 1970, 1986). For that purpose a pionnering work of bi-hemisphere comparative measurements (COALA-project; Mt. Norikua and Liawenee, Tasmania) was carried out in the air-shower energies ($\sim 10^{13}$eV) for almost ten years (1981-1991). Significant but rather small diurnal amplitudes (~ 0.02 %) was reported at Liawenee in comparison with that (0.06 %) at Mt. Norikura (Fenton et al., 1990). This would be still in an open question whether the anisotropy is of energy dependent nature (Nagashima et al., 1989; Murakami et al., 1990) or of intrinsic N-S symmetric or asymmetric nature (Jacklyn, 1970).

Very recently some interesting data were reported from Matsushiro underground observations which suggest the N-S asymmetric nature in the sidereal time variation. Figure 3 shows the observed sidereal diurnal vectors; (a) at (new) Matsushiro (5-year averages; Mori et al., 1990) and (b) at (old) Matsushiro (8-year averages; Yasue et al., 1992). As can be seen in the figure the amplitudes appear to increase as the detector's latitude of viewing moves southward. The observed fact would not be understandable in terms of N-S symmetric distribution but rather be indicative of N-S asymmetric one. To demostrate further such a directional dependent behaviour in other data so far reported, data from various stations are separated into two groups; one towards the south (S-) direction and the other towards the vertical (V-) direction at each station. Those are plotted in Figure 4, as functions of median primaries (projected on the equatorial plane) (Swinson, 1992 ; Mori et al., 1984 ; Humble and Fenton, 1984 ; Davies et al., 1979 ; Ueno et al., 1984 ; Mori et al., 1990 ; Cutler and Groom, 1991 ; Andreyev et al., 1987). In the figure a separation is evident between data of two groups ; the amplitudes of S-group (open circles, fitted with dotted line) are more than twice as large as those of V-group (black circles, fitted with solid line) in the rigidity region 10^{11} eV to 10^{12}eV. Such sorts of larger amplitudes of south-pointing telescopes in the northern hemisphere were already reported from Sakashita underground station (80 m. w.e. depth ; median primaries ~500 GV ; Ueno et al., 1984, 1990). Figure 5 (a) show those data in a summation dial with enough statistics (cited from Ueno et al., 1990). The same plot but for Matsushiro is given in Figure 5 (b), for reference, (Mori et al., 1989). It is noted that significant N-S asymmetric behaviours in the sidereal time variations are observed independently at three stations (at two Matsushiro's and Sakashita). Figure 6 demonstrates another presentation in that the amplitudes in free space are calculated, and are plotted as functions of viewing latitudes for various stations and directional telescopes (Kudo and Mori ; 1985, Yasue et al., 1992 ; Lee and Ng, 1987). In the figure the expected amplitudes in free space (observed/attenuation factor in coupling coefficients) are illustrated, where the statistical errors are referred to their original values. In the estimation of the amplitudes the spectrum of the anisotropy is assumed to be independent of rigidity down to some lower limiting rigidity P_L below which the anisotropy vanishes. It is found that the resultant distribution of the amplitudes does not seem to be N-S symmetric but rather seem to be N-S asymmetric as mentioned above. A calculated curve is fitted tentatively to the distribution, which was evaluated by assuming two anisotropies in free space ; one is of N-S symmetric and the other is of N-S antisymmetric. Here the parameters characterized these two anisotropies were referred to those obtained by Ueno et al. (1984) ; N-S symmetric type has the amplitude of 0.079 % in the 3.5 h LST direction and N-S antisymmetric type has the amplitude of 0.035 % in the 14.9 h LST direction, both spectra being rigidity independent with $P_L = 200$ GV. In the figure we can see a better fitting of the calculated curve to the expected amplitudes, indicating that the present assumption may not be far misdirected for describing the anisotropy. It is noted that the small amplitude at Utah (429 m.w.e depth, primaries ~1.3 TV), in spite of higher primaries, in comparison with that at Matsushiro of lower primaries, may be understood reasonably in the present work.

Almost of data, however, are limited in the northern hemisphere and so scarce in the southern hemisphere, as is listed in Figure 6. To establish the observed fact of the N-S asymmetric behaviours in the sidereal time variations really well and to discuss three-dimensional structure of anisotropy, it may be essentially necessary to have further information in the southern hemisphere. In 1990, Japanese collegues of Shinshu University proposed a joint experiment with Australian collegues of University of

Tasmania with similar equipments at similar rigidities, if both groups could obtain fundings and also a suitable site could be found. Fortunately both of them financially supported. The Liapootah underground site was finally chosen with a great effort by the collegues of University of Tasmania. The observatory and the detection equipments had been constructed in cooperation between two groups. The measurement commenced on December 5, 1991.

It is interesting to note here that in addition to the present bi-hemisphere measurement of N-S asymmetric sidereal anisotropy as described above, we may expect to obtain important information about heliospheric modulation of anisotropy in the rigidity region 10^{12}V, where modulation would be most predominant. The modulation of anisotropy in the heliomagnetosphere may depend on the solar magnetic field polarity (Nagashima al., 1982 ; Bercovitch, 1984). The year of 1990's is certainly significant for such study because the magnetic field polarity sense of the Sun will change as $q>0$ (positive sense in the northern hemisphere) from $q<0$ (negative sense in the northern hemisphere) in 1980's. Most deep underground observations, however, have been in operation since 1980's, and have no enough experiences in the period with $q>0$. Therefore the data in 1990's may provide a new aspect of information about the above problem including the origin of sidereal anisotropy itself whether gammer rays (Alexeenko and Navara, 1985) or charged particles as discussed by Nagashima et al. (1989).

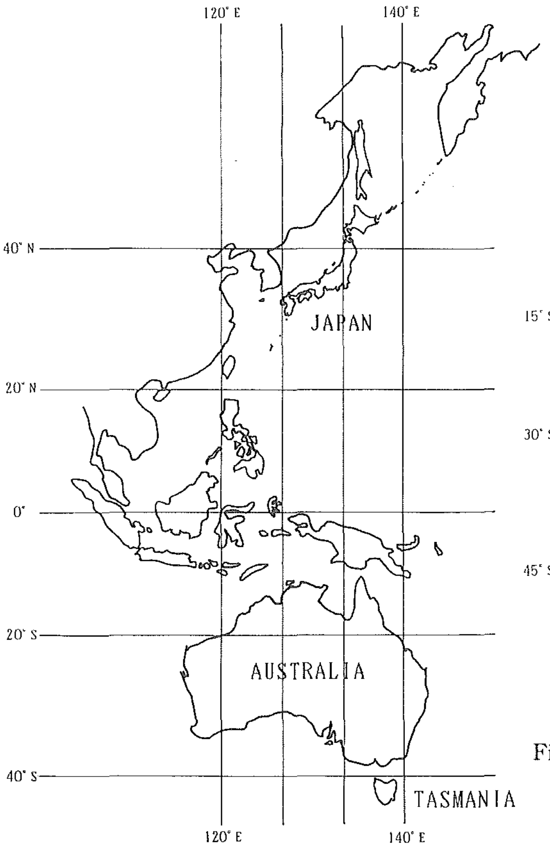
Liapootah Underground Station

1. *Underground site*

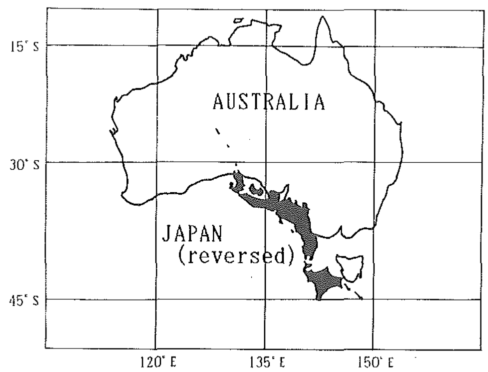
The candidates for the underground site in the southern hemisphere had been searched since 1991 by the collegues of University of Tasmania. The underground site to be chosen would hopefully meet the following requirements as ;

(1) Being conjugate location to Matsushiro (36° N, 138° E) ; hopefully at equal latitude and longitude geographically or geomagnetically.
(2) Being nearly equal underground depth to Matsushiro (220 m.w.e. depth).
(3) Having a wide enough area in the underground tunnel site for constructing the cosmic ray observatory.
(4) Being available of public telephone lines.
(5) Being tranportable by car to the site.
(6) Having a good environment around the underground site and the underground tunnel ; hopefully constant atmospheric temperature and low humidity.
(7) Being assured of a safe security because of unattended operation.

Among the candidates Liapootah Dam site was finally chosen, which almost meets the above requirements as described below, and may be the best place available at the present moment. The Liapootah underground Dam site belongs to the Hydro-Electric



(a)



(b)

Fig. 7. Geographical map showing ; (a) Japan and Australia and (b) Japan (reversed) and Tasmania Island, Australia, to show each conjugate relationship.

Commission (abbreviated as the HEC) of Australia, and a formal permission from the HEC was given for the use of that site on November 1991. Figure 7 shows the geographical map showing ; (a) each location of Japan and Australia and (b) a conjugate relation between Tasmania and Japan (reversed). Liapootah is situated in a central part of Tasmania Island, as shown in Figure 8, and is approximately 90 km northwest of Hobart-city, where Department of Physics, University of Tasmania is located. Table 1 gives some characteristics of the Liapootah underground station together with those of Matsushiro, Japan. Figure 9 shows a detailed map of Liapootah Dam and environs (printed by the Department of Environment and Planning, Tasmania), in which the locations of the underground tunnel and the cosmic ray observatory are indicated. Figure 10 (a) is the photograph of the Liapootah tunnel site and the overburden, underneath which the cosmic ray observatory is situated. Figure 10 (b) is also the photograph of the foot-path to the cosmic ray observatory inside the

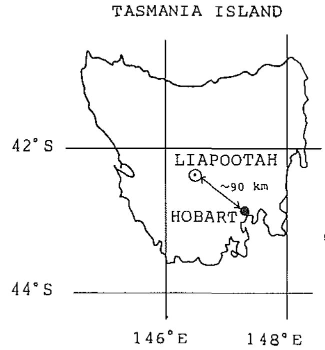


Fig. 8. Location of Liapootah in Tasmania Island, Australia. Liapootah is situated 90km northwest of Hobart-city, where Department of Physics, University of Tasmania is located.

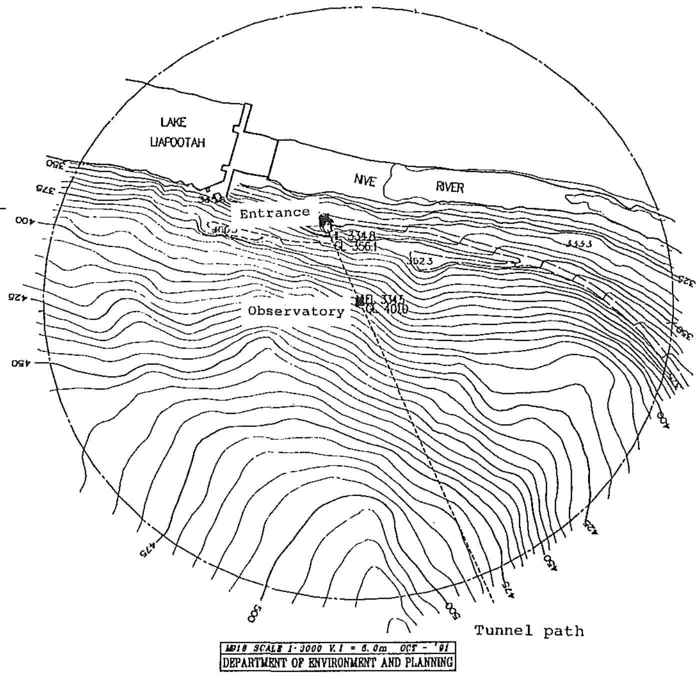


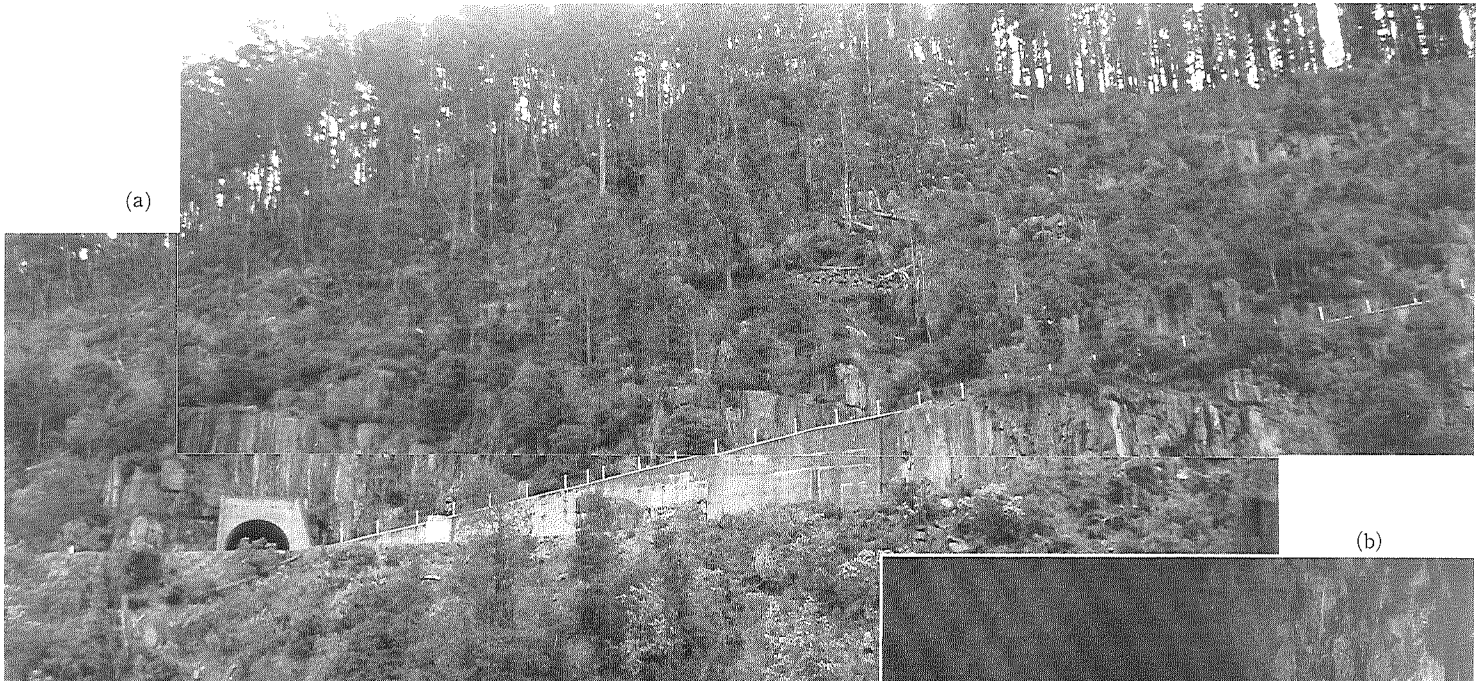
Fig. 9. Detailed map of Liapootah Dam and environs, where the cosmic ray underground observatory is locatd (printed by the Department of Environment and Planning, Tasmania).

tunnel. Figure 11 illustrates a sketch of the cross-sectional profiles of the overburden of the tunnel in two directions, for example ; the north-south (N-S) and the east-west (E-W) direction. In the figure the observatory is indicated with a symbol **O**, and both the vertical depth and the distance are given in units of meter from **O**. The vertical rock depth is approximately 65 m, and the depths overburden are somewhat different from direction to direction ; the south direction is much deeper than the other directions (which corresponds to higher median primary rigidity ; see, Table 3 in the next section). As will be discussed later, the effective vertical depth of the Liapootah underground is estimated at 154 m.w.e., based on the measured muon rates at this site

Table 1. Characteristics of two underground stations of Liapootah and Matsushiro.

Site	Location	Altitude (m)	Depth (mwe)	V-Cnt. Rate (cph)
Liapootah	42°20′S, 146°28′E	350	154	20000
Matsushiro	36°32′N, 138°01′E	360	220	20000

(a)



(b)

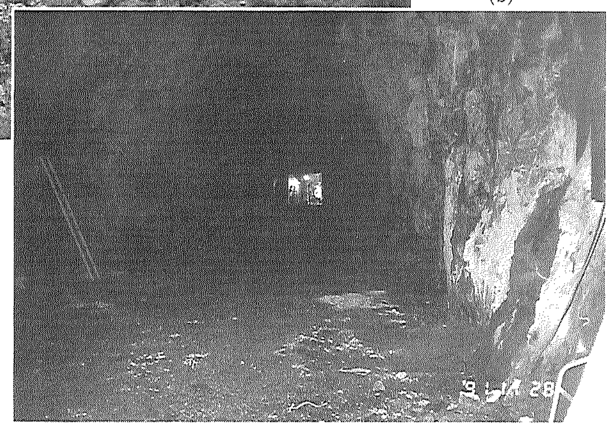


Fig. 10. Photographs showing ; (a) the underground site of Liapootah Dam and the overburden, underneath which the observatory is situated. In the photograph an entrance of the tunnel can be seen, and (b) the foot-path to the cosmic ray observatory inside the tunnel.

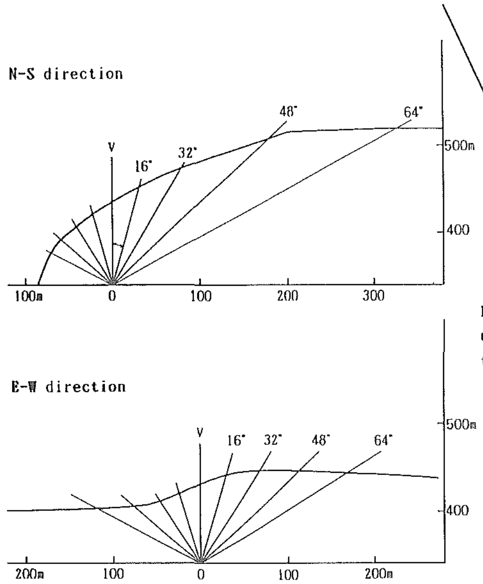


Fig. 11. Sketch of the simplified cross-sections of the underground tunnel of Liapootah Dam in two directions; the north-south (N-S) and the east-west (E-W) directions. Both the vertical depth and the distance from the observatory (**O**) are given in units of meter, and also the lines inclined by the angles 16°, 32°, 48°, and 64° to the vertical (V) are shown.

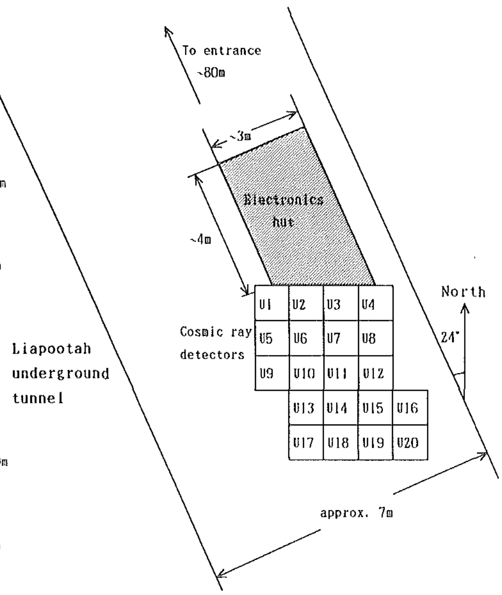


Fig. 12. Geometry of the underground tunnel (viewed from the upper) of Liapootah Dam. The tunnel is directed by 24° to the north, and has the width of approximately 7 m and the height of about 6 m (~80m to the entrance). The cosmic ray observatory has two rooms; one for the telescope (20×2 detectors in two layers; here only the upper detectors are shown) and the other for the electronics system ($\sim3\times4m^2$ in area).

and also with a reference of the measured rates from other underground stations with known depths (see, Figure 20 in the next section). Figure 12 illustrates the geometry of the Dam tunnel (from the upper), where the cosmic ray observatory is constructed. As can be seen in the figure, the direction of the tunnel is inclined by 24° to the north, and the width of the tunnel is approximately 7 m with long enough length (about 6 m high). Two rooms are constructed; one for the telescope and the other for the electronics system. Because of the geometrical condition the cosmic ray detectors are arranged in somewhat staggered manner inside the room. In both rooms the temperature has been kept at 15°-20°C throughout the year with some heating sources (the daily variations are not recorded at present), and the humidity is measured at around 65-70 %.

2. *Muon telescope*

The muon detectors and the telescope used at Liapootah are described with a

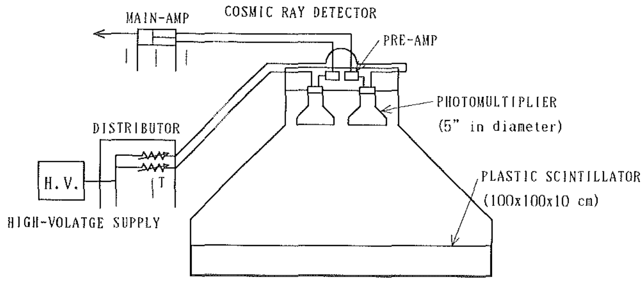


Fig. 13. Cosmic ray muon detector ($1\times1m^2$ area), which consists of the plastic scintillator ($100\times100\times10$cm slab), viewed with double photomultipliers (5″ in diameter). Each output from the detector is connected to the pre-amplifier(inside the box) and (with the cable) to the main-amplifier outside. Exactly the same type of detectors are used at two stations.

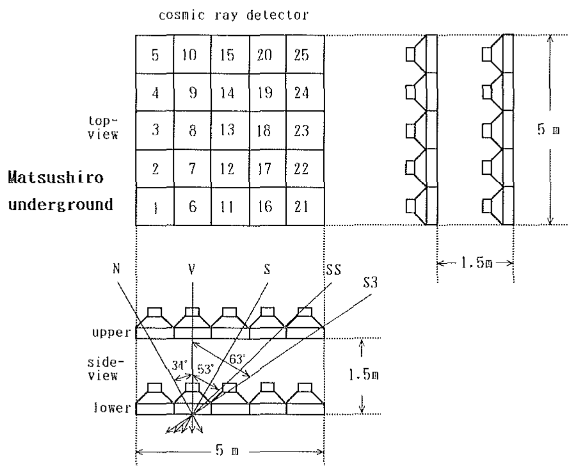
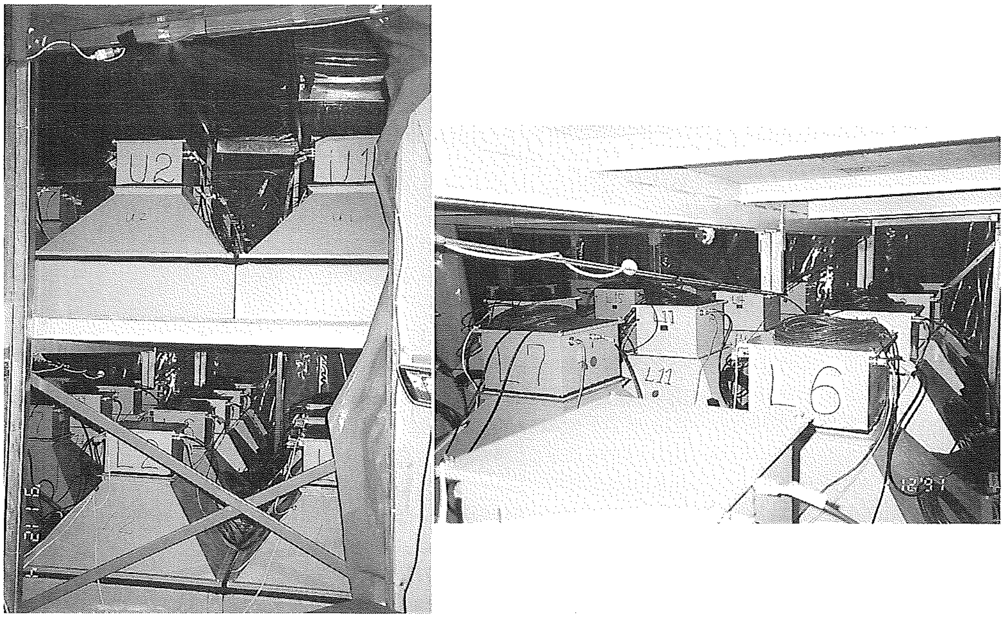


Fig. 14. Arrangement of the muon detectors (top and side views) at Matsushiro. Fifty (25×2) detectors ($1\times1m^2$ area each) are placed in two layers (upper and lower) separated vertically by 1.5m. Telescope construction is also illustrated for V-, N-, S- SS-, and S3-telescope, for example. At Liapootah, the detector arrangement is the same as that at Matsushiro, except for the staggered setting owing to the tunnel condition as shown in Figure 12.

comparsion of those at Matsushiro, some details of which are already presented elsewhere(Mori et al., 1989). Figure 13 illustrates one of the muon detectors, which is exactly the same type as that at Matsushiro and consists of plastic scintillator slab of 1×1 m^2 area and 10 cm depth, viewed with double 5″ photomultipliers. As was well experimented at Matsushiro (Yasue et al., 1981 ; Mori et al., 1989), this double photo-tube system was confirmed to be effective for high signal-to-noise ratio (S/N ratio) at Liapootah (see, Figure 18). Forty detectors are arranged in two layers ($20\times$ 2 detectors) separated vertically by 1.5m, which is the same as those at Matsushiro



(a)

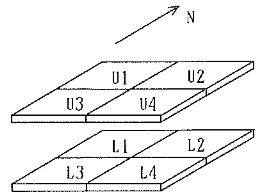
(b)

Fig. 15. Photographs of the muon telescopes; (a) the telescope and the upper detectors at Liapootah and (b) at Matsushiro.

Table 2. Coincidence system for 17 directional telescopes at Liapootah. In the table, × indicates 'and-' and + indicates 'or-' circuit. All the upper detectors (US), all the lower detectors (LS) and WT (wide-total telescope ; US× LS) are also given.

Coincidence-System for Liapootah	
US	=U1+U2+U3+…+U20
LS	=L1+L2+L3+…+L20
WT	=(U1+U2+U3+…+U20)×(L1+L2+L3…+L20)
V	=(U1×L1)+(U2×L2)+(U3×L3)+…+(U20×L20)
N	=(U1×L5)+(U2×L6)+(U3×L7)+…+(U16×L20)
S	=(U5×L1)+(U6×L2)+(U7×L3)+…+(U20×L16)
E	=(U2×L1)+(U3×L2)+(U4×L3)+…+(U20×L19)
W	=(U1×L2)+(U2×L3)+(U3×L4)+…+(U19×L20)
NE	=(U2×L5)+(U3×L6)+(U4×L7)+…+(U16×L19)
NW	=(U1×L6)+(U2×L7)+(U3×L8)+…+(U15×L15)
SE	=(U6×L1)+(U7×L2)+(U8×L3)+…+(U20×L15)
SW	=(U5×L2)+(U6×L3)+(U7×L4)+…+(U19×L16)
N2	={(U1+U2+U3+U4)×(L9+L10+L11+L12)}
	+{(U5+U6+U7+U8)×(L13+L14+L15+L16)}
	+{(U9+U10+U11+U12)×(L17+L18+L19+L20)}
S2	={(U9+U10+U11+U12)×(L1+L2+L3+L4)}
	+{(U13+U14+U15+U16)×(L5+L6+L7+L8)}
	+{(U17+U18+U19+U20)×(L9+L10+L11+L12)}
E2	={(U3+U7+U11+U14+U18)×(L1+L5+L9)}
	+{(U4+U3+U12+U15+U19)×(L2+L6+L10+L13+L17)}
	+{(U16+U20)×(L3+L7+L11+L14+L18)}
W2	={(U1+U5+U9)×(L3+L7+L11+L14+L18)}
	+{(U2+U6+U10+U13+U17)×(L4+L3+L12+L15+L19)}
	+{(U3+U7+U11+U14+U18)×(L16+L20)}
N3	={(U1+U2+U3+U4)×(L13+L14+L15+L16)}
	+{(U5+U6+U7+U8)×(L17+L18+L19+L20)}
S3	={(U13+U14+U15+U16)×(L1+L2+L3+L4)}
	+{(U17+U18+U19+U20)×(L5+L6+L7+L8)}
E3	={(U4+U8+U12+U15+U19)×(L1+L5+L9)}
	+{(U16+U20)×(L2+L6+L10+L13+L17)}
W3	={(U1+U5+U9)×(L4+L8+L12+L15+L19)}
	+{(U2+U6+U10+U13+U17)×(L16+L20)}

(see, Figure 14). As mentioned earlier, owing to the tunnel conditions of somewhat narrow width and low height, the muon detectors are staggered as shown in Figure 12, where only the upper detectors are illustrated with the numberings from U1 to U20 (with the corresponding lower detectors from L1 to L20, not shown here). For reference, the detector arrangement at Matsushiro is shown in Figure 14 ; fifty detectors in two layers (25×2 detectors). Figure 15 is the photograph of the detectors thus arranged ; (a) at Liapootah and (b) at Matsushiro. At Liapootah the mulit-directional telescopes are also constructed as likely to Matsushiro by means of two-fold coincidence system between the upper and lower detectors. A schematic example showing the directional telescopes is given in Figure 16, in which four detectors are arranged in two layers, and two-fold coincidence system for the directional telescopes is described for V-, N-, S-telescope etc. On the basis of the numbering of the detectors shown in Figure 12, the present coincidence-system for 17 directional telescopes at Liapootah is summarized in Table 2, in which all the upper detectors (US), all the lower detectors (LS) and the wide-vertical telescope (two-fold coincidence between US and LS), are also shown. The geometrical setting of the inclined telescopes are exactly the same as that at Matsushiro (see, Figure 14) ; N-, S-, E-, and W-telescope are inclined by 34° to the vertical with angular resolution of ±20° in latitude and ±45° in azimuth, and more inclined telescopes, N2- (or NN-), S2- (SS-), E2- (EE-), and W2- (WW-) telescope are inclined by 53°, and N3-, S3-, E3- and W3-telescope are inclined by 63° to the vertical (see, Figure 14). Other four inclined telescopes ; NE-, NW-, SE-, and SW-telescope, are inclined by 40° to the vertical with angular resolution angle of ±20° in latitude and ±45° in azimuth. In Figure 17, the calculated asymptotic viewing directions are illustrated for 17 directional telescopes at Liapootah together with those at Matsushiro, for five rigidities ; 45, 75, 150, 350, and 750 GV. In the figure one can recognize that the north-pointing telescopes (N-, NN-, and N3-telescope) at Liapootah and the south-pointing telescopes (S-, SS-, and S3- telescope) at Matsushiro may scan the overlapped regions with each other in the celestial space.



Vertical (V-) telescope
U1xL1 + U2xL2 + U3xL3 + U4xL4
North (N-) telescope
U1xL3 + U2xL4
South (S-) telescope
U3xL1 + U4xL2
East (E-) telescope
U2xL1 + U4xL3
West (W-) telescope
U1xL2 + U3xL4
Southeast (SE-) telescope
U4xL1
Southwest (SW-) telescope
U3xL2
etc

Fig. 16. Schematic illustration for constructing the directional telescope with four detectors in two layers (upper, U and lower, L) ; V- N-, S- E-, W- SE-, SW-telescope etc. In the figure, × indicates 'and-circuit' and + indicates 'or-circuit'.

Figure 18 illustrates the so-called voltage characteristic curves (measured counts vs. voltage supplied to photo-tubes) for some directional telescopes ; V- and WT-telescope, and US and LS. Note here that the final output from each directional telescope is of four-fold coincidence because each detector has the output from two-fold coincidence between double photomultipliers (see, Figure 13). This results to negligibly small accidental coincidence rates and high S/N ratio (excellent separation between cosmic ray signals and noises as shown in the figure) even in the deep underground. In the present measurement, the detectors have been in operation at a common voltage of 815 volts with the coarse and fine ajustments to each photo-tube

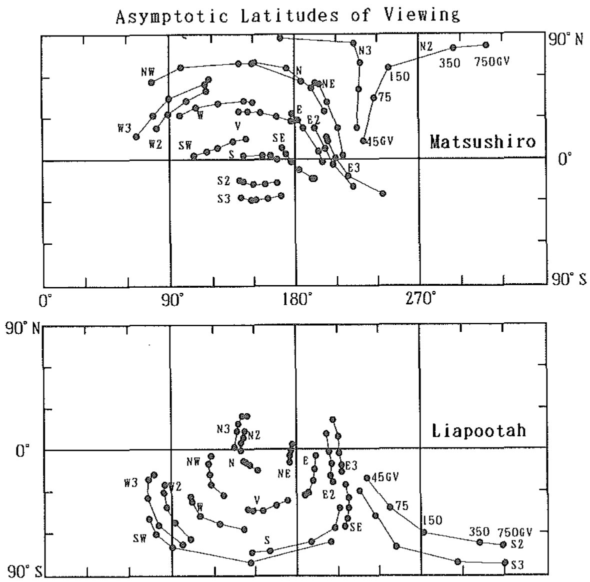


Fig. 17. Aymptotic viewing directions for 17 directional telescopes for Liapootah in the southern hemisphere and for Matsushiro in the northern hemispere. The calculations were made for five rigidities; 45, 75, 150, 350, and 750 GV.

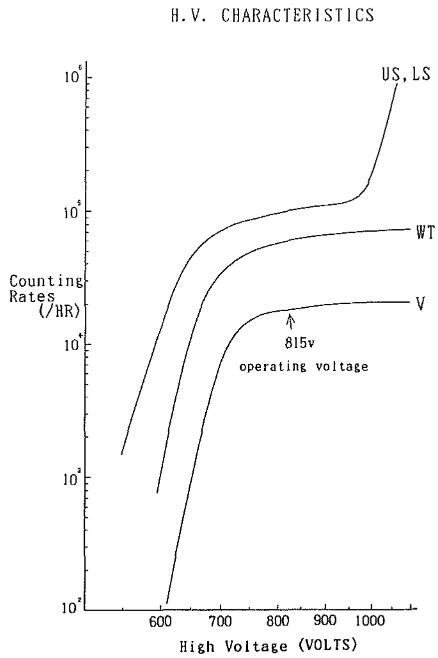


Fig. 18. High voltage characteristics (recorded counts vs. voltage supplied to photo-tubes) for some directional telescopes; WV-, V-telescope, US and LS. The present telescope has been operating at a common voltage of 815 volts.

through resistance-network of HV-distributor (see, Figure 13). Figure 19 illustrates a block diagram of the present electronics system at Liapootah. The present system is controlled by means of the micro-computer system and connected via public telephone line to the universities at Hobart (University of Tasmania) and at Matsumoto (Shinshu University), Japan. This facility may make us possible to look at and check the recorded data visually, to take those data and also to controll all the system at any time we wish.

3. *Calculations of the muon fluxes and coupling coefficients at Laipootah*

First, we estimate the underground vertical depth at Liapootah based on the measured muon rates. Figure 20 plots the measured muon rates by V-telescopes at Liapootah and at other underground stations, as functions of the depths underground, where all the rates are normalized per hour per unit telescope (1×1 m^2 and 1.5 m separation) shown at the top of the figure. The measured rate at Liapootah is plotted with the solid circle, and a line is drawn with a reference of other underground data

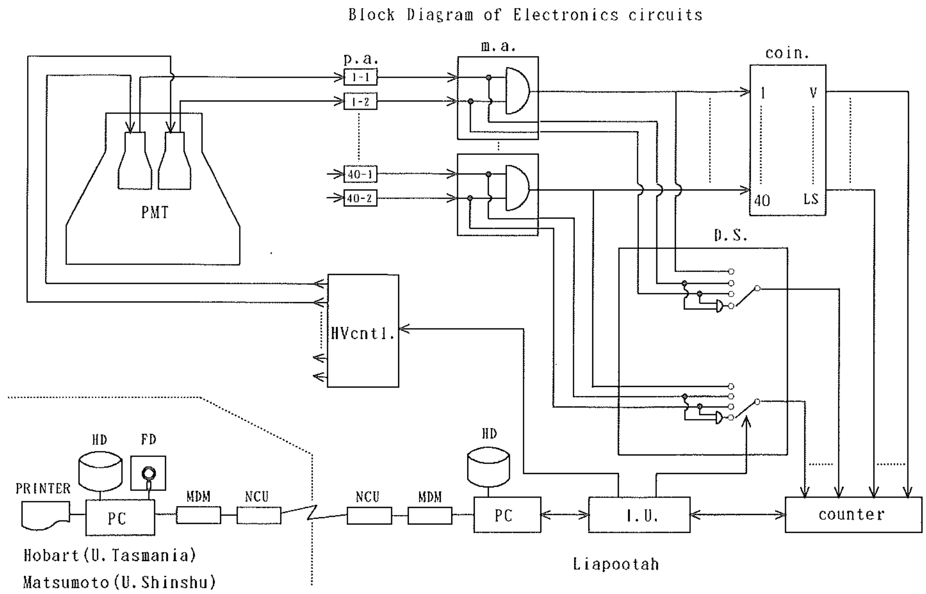


Fig. 19. Block disgram of electronics circuit at Liapooth underground observatory. Controllings of all the system including data sending, are performed by means of the micro-computer system, which are connected, via public telephone lines, to both universities at Hobart (U. Tasmania) and Matsumoto (Shinshu U.).

with known depths (with open circles) ; Misato (34 m.w.e. depth ; Mori et al. 1976), Sakashita (80 m.w.e. depth ; Ueno et al., 1984), two Matsushiro's (old and new ; 220 m. w.e. depth) and Poatina (375 m.w.e. depth ; Fenton and Humble, 1975). From this figure the effective vertical depth of Liapootah underground is obtained to be approximately 154 m.w.e. This may be consistent with the vertical depth calculated from the rock depth (see, Figure 11) and its density (~2.4).

The expected muon fluxes and the coupling coefficients are calculated for Liapootah by using muon response functions with a work of Murakami et al. (1979). Detailed calculation and numerical figures are summarized elsewhere (Furuhata, 1991). Table 3 gives the muon fluxes of the observed (Iobs) and the calculated (Ical) at Liapootah for 17 directional telescopes, together with the same values but for Matsushiro. In the table one can find that the measured and the calculated fluxes well agree with each other except for those of the telescopes with large inclinations (S3-and W3-telescope), which may be due to the response functions used in the calculation. In the table, the calculated effective latitudes of viewing and median primary rigidities are also shown. Figure 21 shows the so-called integral response functions, giving the percentage of the counting-rate F ($>P_m$) due to primaries of rigidities P_m for four directional telescopes ; N-, S-, E-, and W-telescope, for example. As listed in Table 3,

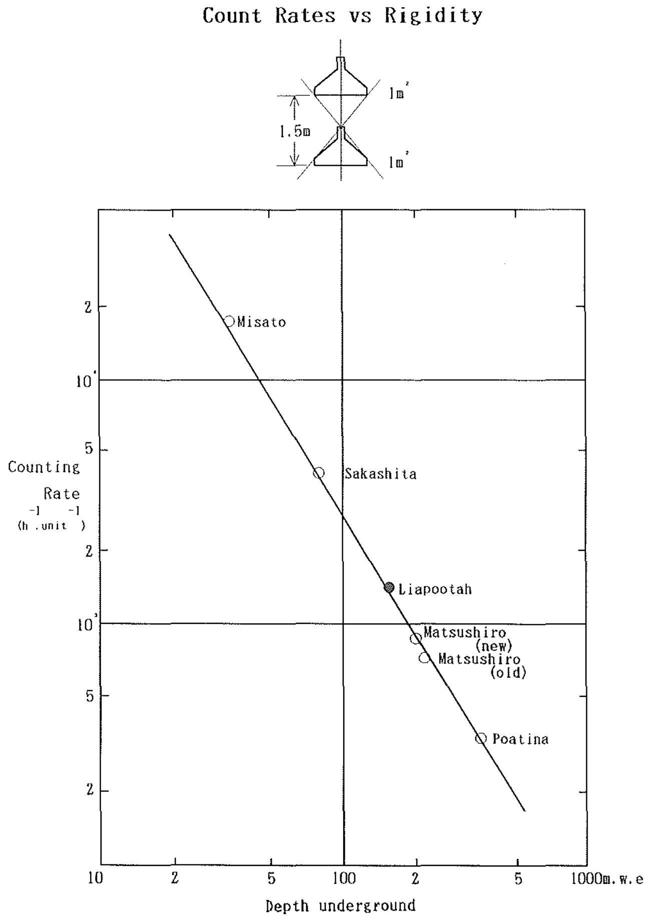


Fig. 20. Observed muon fluxes at Liapootah (black circle), normalized per hour and per unit detector of $1\times1\times1.5$m (shown at the top of the figure). The line is drawn with a reference to the normalized values from other underground stations with known depths ; Misato, Sakashita, new and old Matsushiro's, and Poatina. From this fitting, the effective vertical depth at Liapootah is estimated at 154 m. w. e.

at Liapootah the median primary rigidities are $5\cdot10^{11}$-10^{12}V, which cover almost similar ranges at Matsushiro. The coupling coeffiicints are also calculated, and are summarized elsewhere by Furuhata (1991). For example, Figure 22 illustrates the expected vectors for some harmonics ; the diurnal terms D^1_1 (N-S symmetric type) and D^1_2 (N-S asymmetric type), for the case where the spectrum of the anisotropy (shown with an arrow) is assumed to be independent of rigidity for the whole rigidity range. The same vectors but for Matsushiro are also plotted in the figure, for comparison. One can find in the figure that the N-S asymmetric term D^1_2 shows its opposite nature to each other between Liapootah and Matsushiro, particularly its phase of almost 12 hr

Table 3. Muon fluxes of the observed (Iobs) and the calculated (Ical) for 17 directional telescopes at Liapootah together with those at Matsushiro. Effective latitudes of viewings λ_E and median primary rigidities P_m are also shown in the table.

Geog. lat.	locat. lon.	tele-scope	λ_E	SΩ (m^2str)	I_{obs} (10^3/h)	I_{cal} (10^3/h)	P_m (GV)
42.0°S	147.0°E	V	36.2S	7.05	25.0	24.1	539
		N	14.6S	3.35	18.0	16.9	470
		S	57.6S	3.35	5.0	4.8	794
LIAPOOTAH		E	30.6S	3.35	13.0	12.1	530
		W	34.1S	3.35	7.9	6.9	669
		NE	11.3S	1.62	8.3	8.3	477
		NW	14.1S	1.62	7.2	5.8	561
		SE	48.1S	1.62	3.6	2.9	770
		SW	53.9S	1.62	1.5	1.3	1034
		N 2	4.4N	1.92	9.6	9.0	534
		S 2	57.3S	1.92	1.4	0.7	1780
		E 2	15.5S	1.86	5.5	5.0	677
		W 2	10.1S	1.86	4.0	2.6	890
		N 3	13.7N	0.46	2.4	2.0	593
		S 3	54.5S	0.46	0.4	0.1	2657
		E 3	14.2S	0.34	0.9	0.6	917
		W 3	1.7S	0.34	1.0	0.4	1104
36.5°N	137.8°E	V	34.5N	8.81	19.5	18.7	659
		N	57.0N	4.19	8.9	8.4	685
		S	11.2N	4.19	7.2	6.7	753
MATSUSHIRO		E	28.0N	4.19	9.3	8.9	669
		W	32.8N	4.19	13.3	13.6	565
		NE	46.8N	2.16	4.5	3.9	725
		NW	52.3N	2.16	6.3	6.5	590
		SE	8.0N	2.16	4.4	3.8	738
		SW	11.3N	2.16	5.4	4.9	667
		N 2	60.0N	2.78	5.8	5.7	738
		S 2	8.2S	2.78	3.7	4.0	861
		E 2	19.2N	2.78	5.9	5.9	733
		W 2	26.8N	2.78	8.3	9.0	613
		N 3	61.3N	0.68	1.5	1.4	793
		S 3	15.0S	0.68	0.9	0.9	940
		E 3	16.5N	0.68	1.6	1.5	784
		W 3	24.0N	0.68	2.3	2.4	654

apart in the bi-hemisphere. We also estimate the expected sidereal diurnal vectors for 17 directional telescopes at Liapootah, which are shown in Figure 23. These are calculated with the same procedure as that in Figure 6, assuming two anisotropies of N-S symmetric and of N-S antisymmetric, whose characteristics are given earlier. In the figure we can find larger amplitudes for N-telescopes at Liapootah in contrast to

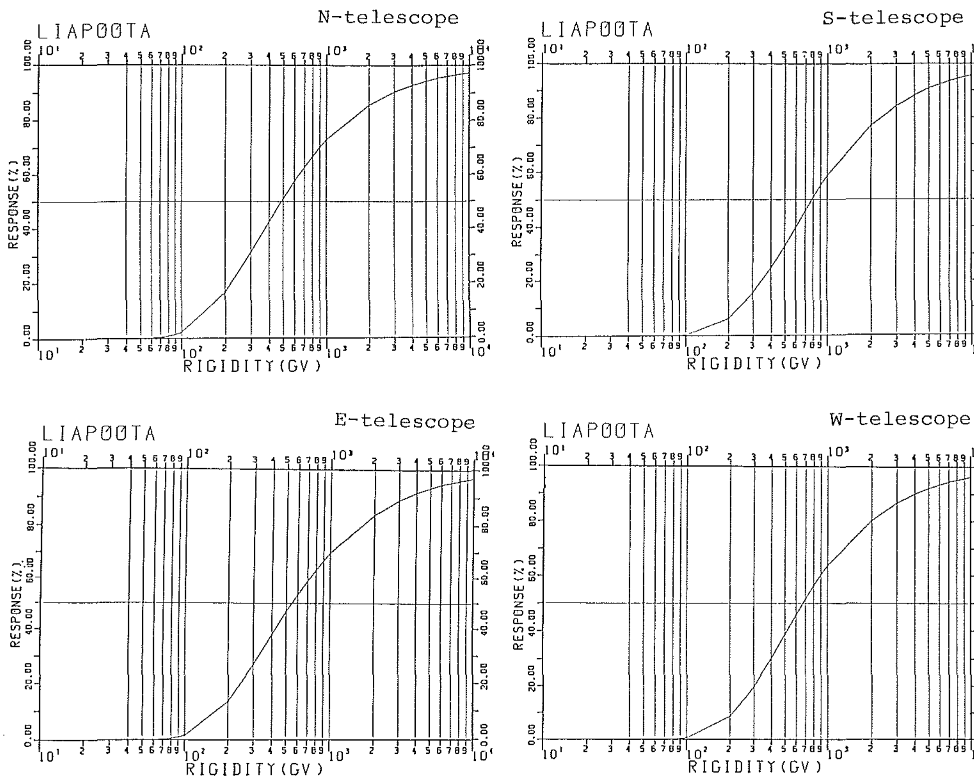


Fig. 21. Integral response functions giving the percentage of the count-rate F ($>P_m$) due to primaries of rigidities P_m for some of the directional telescopes at Liapootah ; N-, S-, E-, and W-telescope, for example.

smaller ones for N-telescopes at Matsushiro. Figure 24 demonstrates such expected diurnal amplitudes at Liapootah (with an error bar), together with those at various stations (see, Figure 6) ; (a) as functions of effective viewing latitudes and (b) as functions of primary rigidities. In the figure the statistical errors at Liapootan are derived from counting-rates for one year period. From this figure at Liapootah we may hopefully expect that the anisotropy could be observed with several times as large significance as the statistical errors for two or three years period.

Observed Data

The continuous measurements of the cosmic ray muon intensity commenced on December 5, 1991, and have been well running since then. In this section some results obtained for a one-year period (Dec. 1991- Nov. 1992) are preliminarily summarized.

1. *Intensity variation of cosmic ray muons*

Figure 25 demonstrates the measured time variations of cosmic ray muon intensity

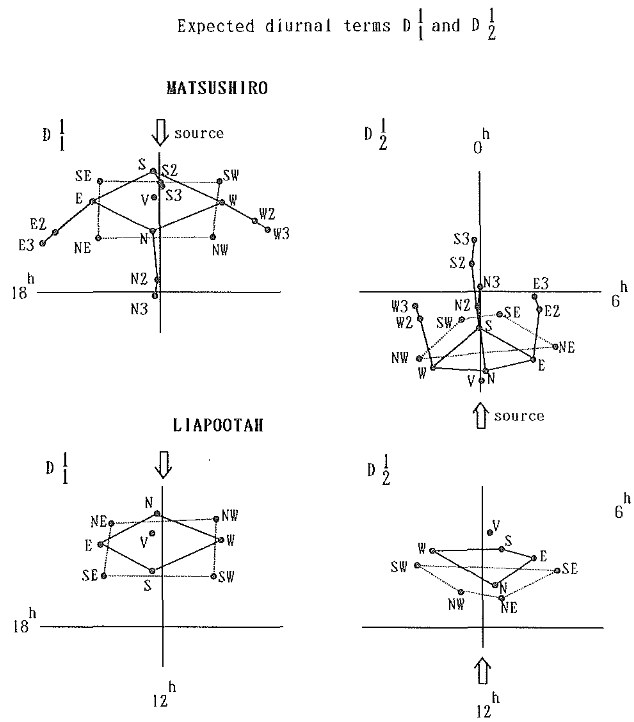


Fig. 22. Expected vectors of some harmonics for 17 directional telescopes; D^1_1 (north-south symmetric diurnal term) and D^1_2 (north-south asymmetric diurnal term) at Matsushiro and Liapootah. These vectors are calculated for the case where the variational rigidity spectrum of the source (shown with an arrow) is flat (rigidity independent) for the whole rigidity range.

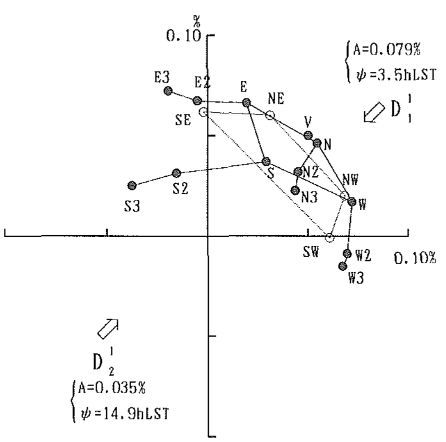


Fig. 23. Expected diurnal sidereal vectors calculated for 17 directional telescopes at Liapootah, by assuming two anisotropies of N-S symmetric and N-S asymmetric in free space; the former has 0.079 % in amplitude in the 3.5 hr LST direction and the latter has 0.035 % in amplitude in the 14.9 hr LST direction. In the calculation, both spectra are assumed to be rigidity independent with P_L = 200 GV.

on a daily basis at Liapootah for US, LS, WT- and V-telescope during one-year period from Dec. 1991 to Nov. 1992. Those data are not corrected for any effects. First, to try a statistical test of those data the frequency distribution of deviations of the hourly

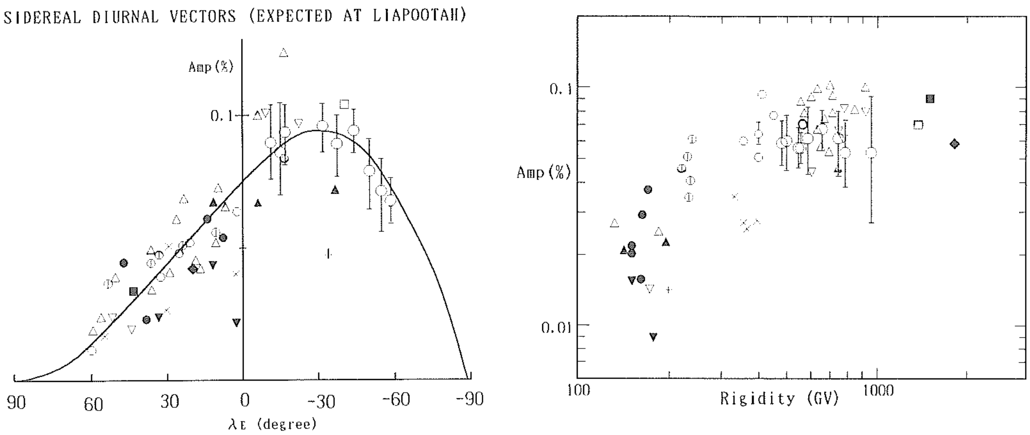


Fig. 24. Expected sidereal diurnal amplitudes at Liapootah, calculated with the same procedure as that in Figures 6 and 23. The statistical errors are derived from counting-rates for one-year period.

muon counts for WT- and V-telescope are plotted in Figure 26, and Gaussian distribution fittings to the histogram are also made. As can be seen in the figure, the measured distribution of counts well fit to the distribution having the corresponding Poisson error, whose σ's are shown in the figure. Secondly, Figure 27 shows the deviations of muon rates from the average on a monthly basis for Liapootah and Matsushiro during December 1991 to November 1992. For Matsushiro the periods are extended more longer time (1989 to 1992), and numerical expectations are also shown for 1989 with dotted lines, which are obtained by taking into accounts the atmospheric temperature data (cited from Munakata et al., 1991), for reference. In the figure a clear tendency of semi-annual variation in intensity may be seen, showing two maxima in the winter- and the summer-season, which was already reported by Sagisaka (1986) and Munakata et al. (1991). This is one of characteristic features for high energy muons. Based on bi-hemisphere comparative data of muon intensity variations we may suspect the temperature profiles in the upper atmosphere with different point of views from the meteorological points (Andreyev et al., 1991). Thirdly, the barometric pressure effects on the recorded muons are also analyzed. In Figure 28 a simple correlation diagam is shown between hourly counts of muons (V- and WT-telescope) at Liapootah and the barometric pressures at Hobart (~90 km in distance from each other). In the figure some significant correlation may be found between these values, and the barometer coefficients are respectively obtained that; $\beta=-0.029$ %/mb (with correlation coefficient $r=-0.40$) for WT-telescope and $\beta=-0.028$ %/mb (with $r=-0.19$) for V-telescope. In Figure 29, we plot the present coefficient at Liapootah and compare it with those at other underground stations so far reported, as functions of the threshold energies of muons (cited from Sagisaka, 1986). It is found that the present coefficient

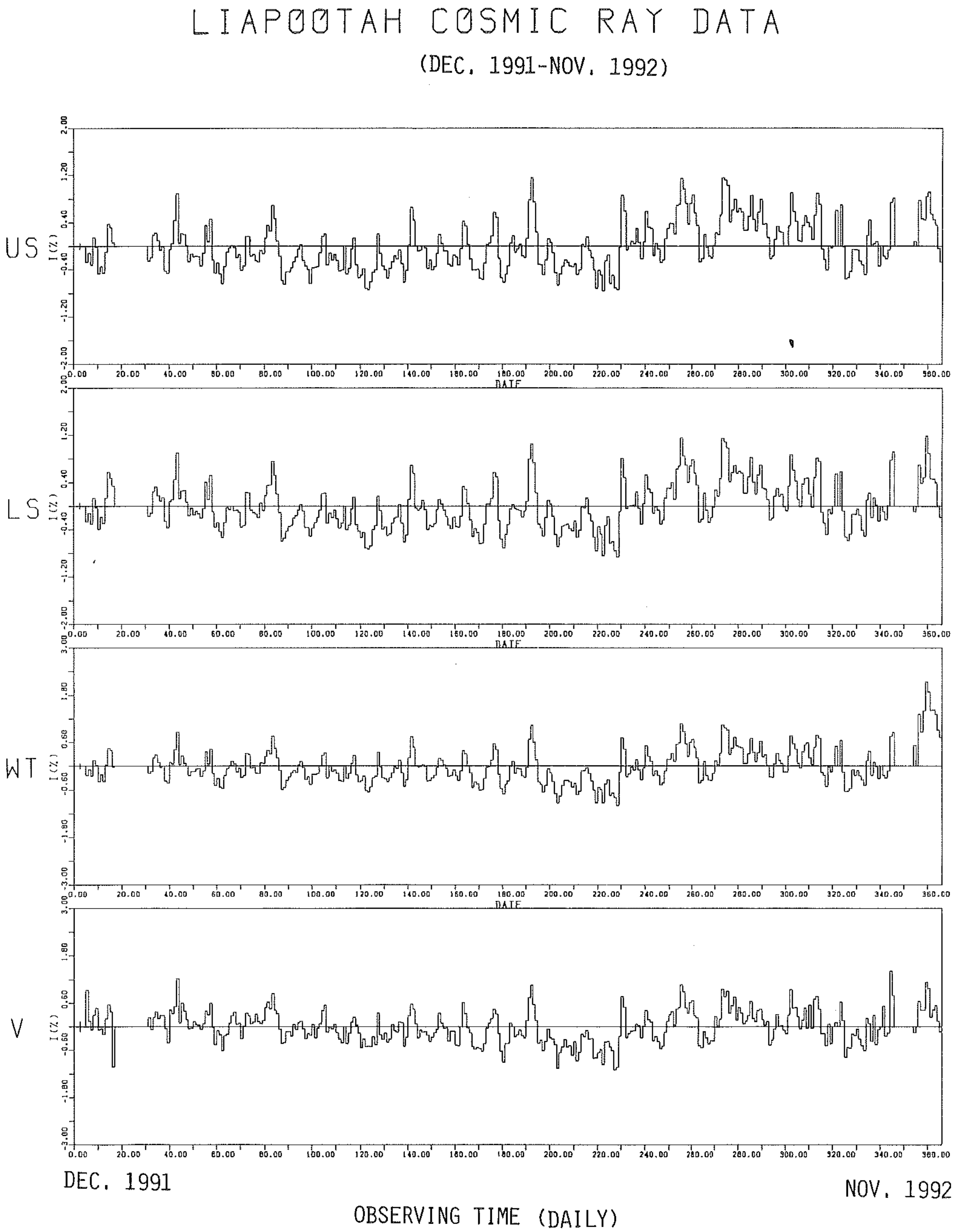


Fig. 25. Example of the measured intensity variations of muons on the daily basis for US, LS, and WT- and V-telescope at Liapootah during December 1991 to November 1992.

at Liapootah may be consistent with other results and rather well fits to the calculated curve evaluated by considering the contribution of the upper atmospheric temperature effect.

2. *Daily intensity variation*

Figure 30 illustrates the histogram of the measured muon counts in the 24-hour period for WT- and V-telescope at Liapootah and Matsushiro during December 1991 to November 1992, plotted in solar time (SO), in sidereal time (SI) and in anti-sidereal time (AS), respectively. At the present stage, unfortunately owing to some unknown noises, not all are shown here. Detailed check and more examination are now underway, and the confirmed results will appear soon. The conventional Fourier

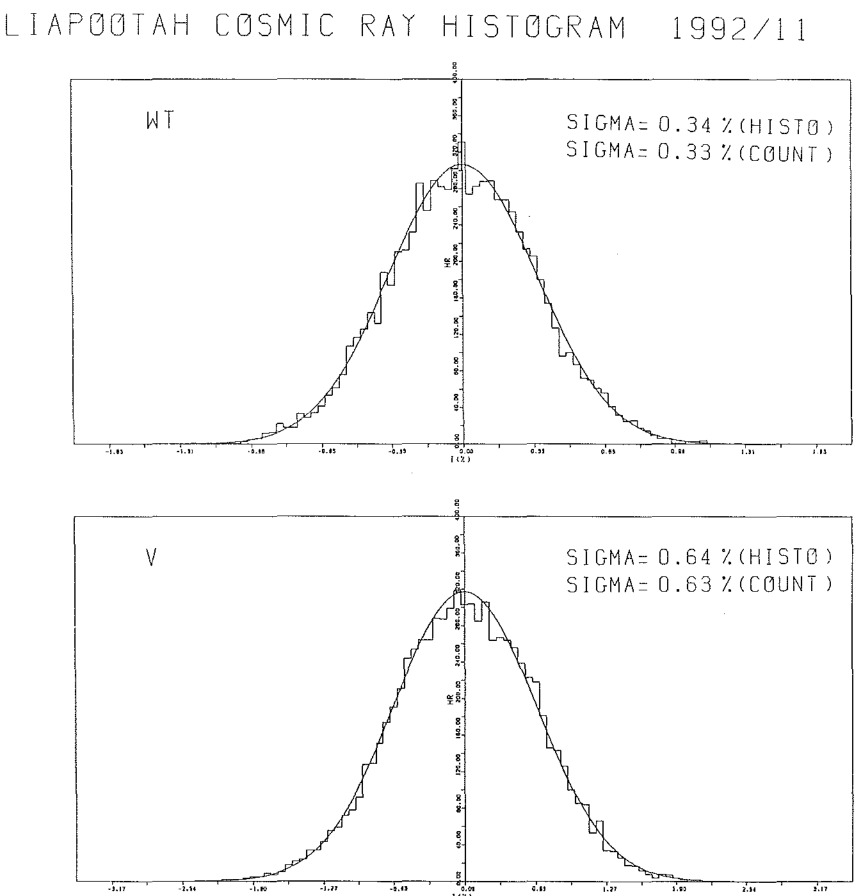


Fig. 26. Frequency distribution of deviations of hourly counts of muons for WT- and V-telescope at Liapootah during December 1991 to November 1992. Gaussian fittings are also demonstrated. Both standard errors from Poisson distribution (COUNT) and the measured distribution (HISTO) are given in the figure.

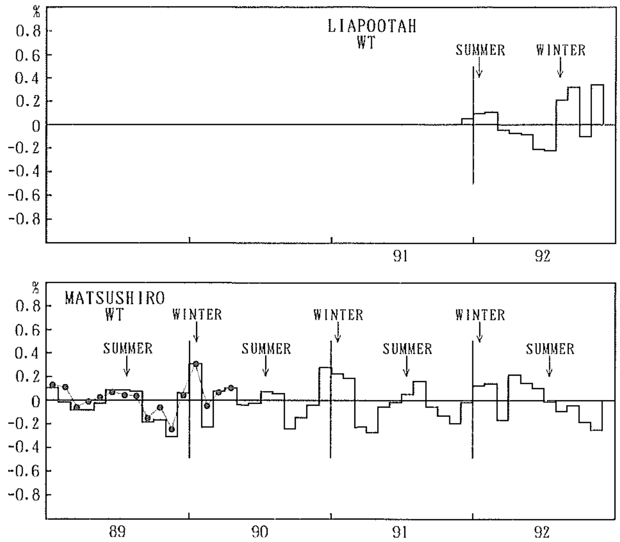


Fig. 27. Deviations of monthly cosmic ray muon rates from the average values for WT-telescope at Liapootah during Dec. 1991-Nov. 1992. The same plot but for Matsushiro is also given for WT- telescope during more extended periods of time (Jan. 1989-Nov. 1992). For Matsushiro numerical expectations are estimated by referring to the upper atmospheric temperature as plotted with dotted lines (Munakata et al., 1991). One can see the deviations showing rather maximum values at two seasons of the winter and the summer during the course of the year.

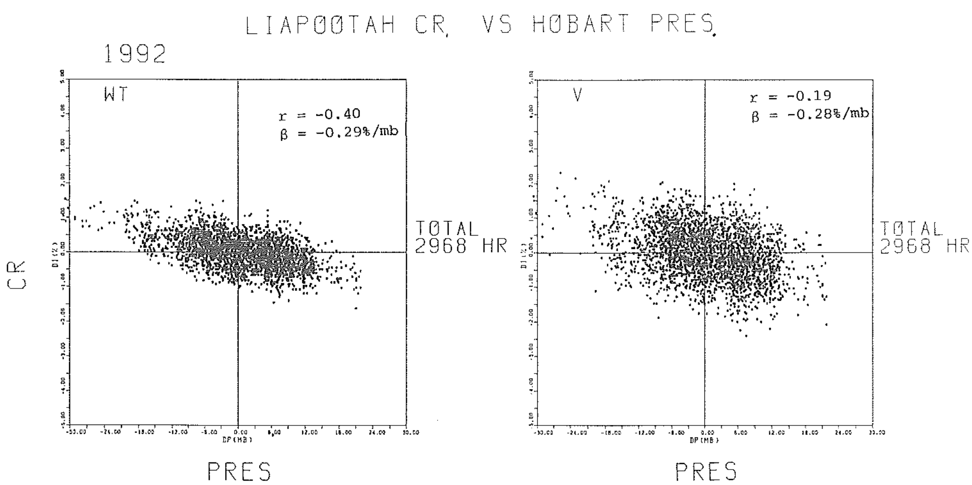


Fig. 28. Correlation diagram is demonstrated between hourly muon intensities (CR; with 2968 data points) at Liapootah and the barometric pressures (PRES) at Hobart (90km in distance between the two places) for WT- and V-telescope. The correlation coefficient r and the barometer coefficient β(mb/%) are also given in the figure.

analysis is applied to those histograms, and the diurnal terms are calculated. These are shown in Table 4 in SO-, SI-and AS-time coordinate system, in which the statistical errors are derived from counting-rates. Figure 31 plots the month-to-month variation of the solar diurnal vectors and its mean for V-telescope at Liapootah during ten months of Jan. 1992 to Oct. 1992, where the errors are derived from counting-rates. In the figure a systematic counterclockwise movement of these monthly vetcors may be recognized, and this may indicate the existence of significant sidereal diurnal term as given in Table 4. Figure 32 plots the monthly sidereal diurnal vectors and its mean (with the dotted line and the cross) for V-telescope at Liapootah and Matsushiro, whose error circles are derived from counting-rates. At Matsushiro yearly mean vectors for 8-year period (1984-1992) are also plotted (with open circles), for reference. In the figure and the table, some indication may be recognized that larger diurnal amplitude (~0.047 % for V-telescope) at Liapootah may be expected than that at Matsushiro. More data would be required to establish a definite conclusion on the N-S asymmetric anisotropy.

Dicussion and Summaries

Japan-Australia cooperative observation between Shinshu University and University of Tasmania commenced in Decmber 1991 to measure north-south (N-S) asymmetry in the intensity variation, particularly of N-S asymmetric sidereal

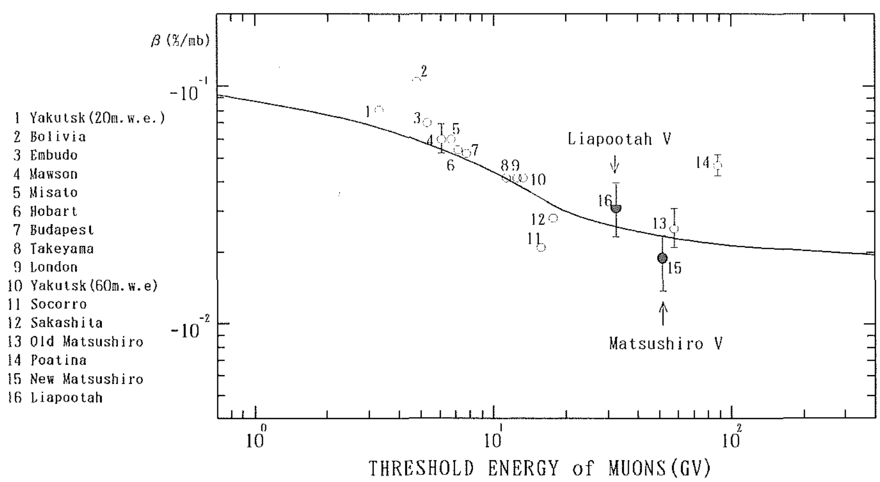


Fig. 29. Barometer coefficient β(%/mb) for V-telescope at Liapootah (solid circle) is plotted as functions of muon threshold energies, together with those from Matsushiro (solid circle) and from various underground stations. The theoretically calculated coefficinet curve is also given, which was evaluated by taking into accounts the atmospheric temperature effect (cited from Sagisaka, 1986).

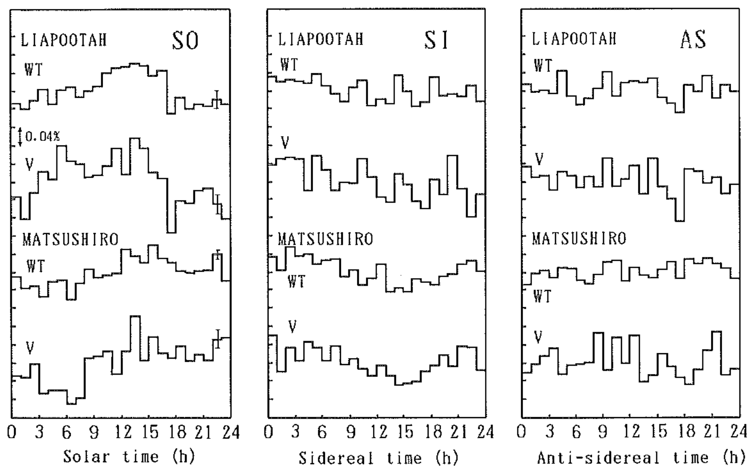


Fig. 30. Hourly histograms of recorded muons in the 24 hours interval for WT- and V- telescope at Liapootah and Matsushiro, illustrated in solar time (SO), in sidereal time (SI) and in anti-sidereal time (AS) for the period of Dec. 1991- Nov. 1992. The statistical errors from couning-rates are shown in SO diagram.

anisotropy of high energy cosmic rays ($\sim 10^{12}$eV). This project was motivated on the basis of the observed evidence that in the northern hemisphere the observed diurnal amplitudes appear to increase as the detector's latitude of viewing moves southwad at rigidities $\sim$400 GV (at Sakashita) to$\sim$1 TV (at two Matsushiro's). This evidence is, however, limited only in the northern hemispere, and has no positive confirmation in the southern hemisphere. In order to get further information in the southern hemisphere and establish the observed fact really well, the collegues of Shinshu University proposed the present project in a cooperation with the collegues of

Table 4. Observed diurnal vectors at Liapootah (abbreviated to L) for V-telescope ; in solar (SO), sidereal (SI) and anti-sidereal (AS) time, for ten months from Jan. 1992 to Oct. 1992. Statistical errors are derived from counting-rates. The same values but for Matsushiro (abbreviated to M) are also shown with the 8-year average (abbreviated to M** ; the error is derived from dispersion of yearly mean).

	Solar (SO)		Sidereal (SI)		Anti-sidereal (AS)	
	(%)	h LT	(%)	h LT	(%)	h LT
L	0.042±0.011	11.0±1.0	0.047±0.011	3.5±0.9	0.005±0.011	16.1±*
M	0.044±0.011	17.1±0.9	0.031±0.011	3.0±1.5	0.013±0,011	7.9±3.1
M**	0.035±0.004	16.3±0.4	0.026±0.004	3.0±0.5	0.012±0.004	23.1±1.2

* not determinable due to larger error than amplitude.

**averaged over 8-year period (1984-1992) at Matsushiro.

University of Tasmania, Australia in 1990. Two groups agreed with each other to push the project, both of us being supported financially. A pair of underground stations in the bi-hemisphere was searched and finally chosen as; one is Matsushiro, Japan in the northern hemisphere and the other is Liapootah, Tasmanis Island, Australia in the southern hemisphere. Two underground stations are situated at almost conjugate position, and at similar underground depths, therefore at nearly the same rigidity regions of primaries. The detection equipments of cosmic ray muons (detectors and muon telescopes) are quite similar to each other as described in the above sections. The installation of the detectors and the telescope were successfully completed within one month on early December, 1991, and the measurements commenced on December 5, 1992.

The continuous operation has been well running since then. All the systems have been monitored via public telephone lines from both universities in Hobart, Tasmania and Matsumoto, Japan. Hourly counts for 17 directional channels have been recorded at two stations, and those data are taken at any time we wish. At the present stage, unfortunately, some unknown noises are observed in the electronics circuits and disturbed the data in some channels at Liapootah, and therefore in the present paper the data are limited to V- and WT-telescope only.

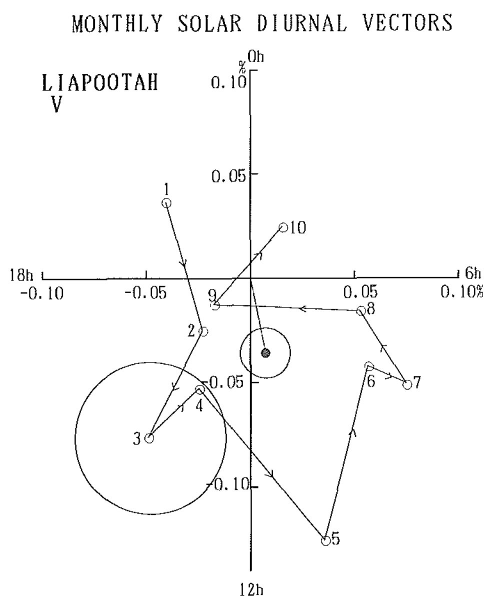


Fig. 31. Monthly solar diurnal vectors for V-telescope at Liapootah during the period from Jan. 1992 to Oct. 1992. The number on each vector represents the month. The error circle on March (number 3) is derived from counting-rates. Yealy mean vector is also shown with black circle, whose error is derived from counting-rates.

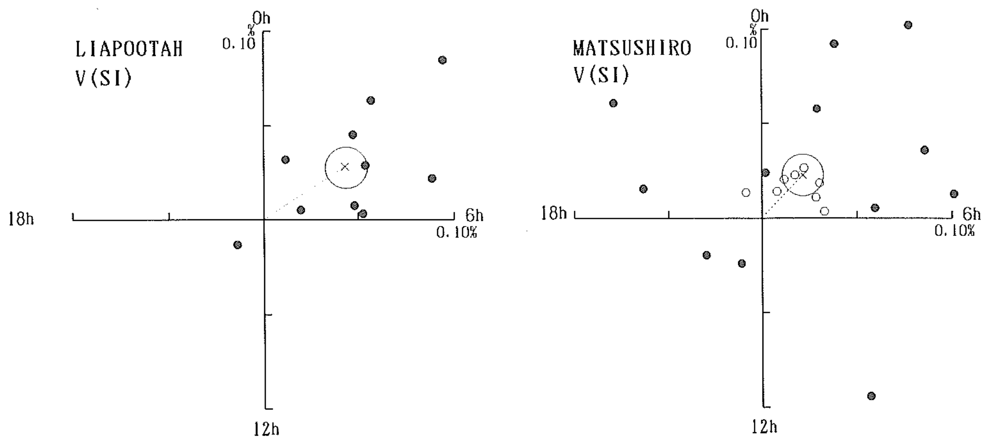


Fig. 32. Monthly plots of observed sidereal diurnal vectors and its mean for the period Jan. 1992-Oct. 1992 at Liapootha, where the error circle is derived from counting-rates. The same plots but at Matsushiro for the corresponding time period are shown, where the error is derived from counting-rates. At Matsushiro each yearly mean vector (with open circle) is also plotted for 8-year period (1984-1992), for reference.

From the above procedures and the results, we may summarize the present project as follows;

(1) Bi-hemisphere comparative observations between Shinshu University, Japan and University of Tasmania, Australia, commenced in December 1991 to measure the north-south (N-S) asymmetry in the intensity variation, particularly the N-S asymmetric sidereal anisotropy of high energy cosmc rays ($\lesssim 10^{12}$eV).

(2) A pair of underground stations has been opened; one at Matsushiro (in operation since 1984) in Japan and the other at Liapootah (newly constructed) in Tasmania Island, Australia.

(3) Two stations have satisfied characteristics each other as; at almost conjugate location, at similar depths underground (154 m.w.e. and 220 m.w.e., respectively), and at almost the same median primary rigidities (~500GV-1TV).

(4) The detectors and the muon telescopes (of multi-directional) are quite similar to each other (20×2 detectors and 25×2 detectors, respectively), some of which may scan the overlapped regions in the celestial space.

(5) All the electronics systems including the data sendings are controlled by means of the micro-computer system via public telephone lines form both universities at Hobart and Matsumoto.

(6) The observed and the expected fluxes of cosmic ray muons well agree with each other at Liapootah, and average counting-rates are obtained as; $\sim 2\cdot10^4$/hr for V-telescope and $5\text{-}7\cdot10^3$/hr for the inclined telescopes.

(7) The continuous measurements have been carried out since Decemebr 5, 1991 and in rather well operation since then. Some of data are preliminarily presented.

Acknowledgements

The authors would like to express sincere appreciation to those who support the present project and give many kind suggestions to us at both Shinshu University and University of Tasmania. Thanks are also due to the Hydro-Electric Commission (HEC), Tasmania for allowing us to use the Liapootah Dam tunnel. The present project has been financially supported by the Grant-in Aids for Research from the Ministry of Education, Science and Culture, Japan (No. 03044067) and for the International STEP-project (Representatives; Prof. S. Kato, Kyoto University) to Shinshu University and by the Grant-in-Aid for the Australian Research Council to University of Tasmania. We (Shinshu University) are also supported with the research-funds from the companies of HITACHI-DEVICE CO., OKI-DENKI CO., and TOSHIBA-JOHOU CO., we greatly appreciate them for their kindness.

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