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Galactic-disk enhancement of cosmic rays at $E > 10^{12}$eV(*)

S. Ogio(1), Y. Tsunesada(1), F. Kakimoto(1), O. Burgoa(1), E. Gotoh(2)
D. Harada(1), T. Kaneko(3), Y. Matsubara(4), P. Miranda(5), Y. Mizumoto(6)
A. Morizawa(7), K. Murakami(8), H. Nakatani(2), K. Nishi(2), S. Shimoda(2)
Y. Shirasaki(9), N. Tajima(2), H. Tokunou(1), Y. Toyoda(10), A. Velarde(5)
Y. Yamada(2) and H. Yoshii(7)

(1) *Department of Physics, Tokyo Institute of Technology - Meguro, Tokyo 152-8551, Japan*
(2) *The Institute of Physical and Chemical Reseach - Wako, Saitama 351-0198, Japan*
(3) *Department of Physics, Okayama University - Okayama 700-8530, Japan*
(4) *Solar-Terrestrial Environment Laboratory, Nagoya University Nagoya, Aichi 442-8507, Japan*
(5) *Institute de Investigaciones Fisicas, Universidad Mayor de San Andres Casilla 8635, La Paz, Bolivia*
(6) *National Astronomical Observatory - Mitaka, Tokyo 181-8588, Japan*
(7) *Department of Physics, Ehime University - Matsuyama, Ehime 790-8577, Japan*
(8) *Nagoya University of Foreign Studies - Nissin, Aichi 470-0197, Japan*
(9) *NASDA - Tsukuba, Ibaraki 305-8505, Japan*
(10) *Faculty of General Education, Fukui University of Technology - Fukui 910-8505, Japan*

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Summary. — We observed an enhancement of cosmic rays from the Vela region with SAS array at Mt. Chacaltaya in Bolivia. It is not possible to conclude that this enhancement is caused by primary gamma-rays, since the observed events not limited with the less muons in the air showers show the same enhancement. In order to confirm this result with improved statistics and to investigate the energy dependence of this enhancement, we have installed a new array, called MAS array. All the data with much higher statistics show the enhancement along the whole galactic disk.

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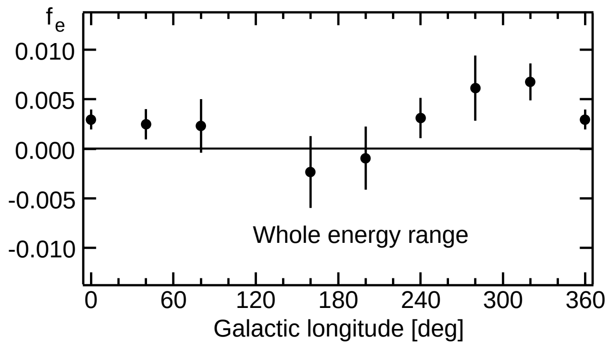

Fig. 1. – The galactic enhancement factor f_e measured with SAS array is plot against the galactic longitude.

1. – Introduction

SNRs are believed to be predominant sites where cosmic rays are accelerated up to the energies of the knee region. If a nearby SNR emits the high energy cosmic rays, we can measured anisotropy in the arrival direction distribution of cosmic rays. Unfortunately, the degree of anisotropy is expected to be several times 0.1% [1].

We started observation of air showers with SAS array [2,3] at Mt. Chacaltaya in 1987. This array is sited at 16.2° south, so that we can observe cosmic rays coming from almost all the galactic disk. In order to measure the enhancement with more higher statistics and wider energy range we started improvement of the SAS array in 1996, and the full operation of the new array, called MAS array [3], was started in 1998. Here we present the summary of our measurement with SAS and MAS arrays until 2000.

We analyzed the anisotropy with estimating of galactic enhancement factors as introduced by Wdovzyk and Wolfendare [4]. The arrival direction distribution $N^{\rm obs}(l,b)$ of the observed air showers is examined in the galactic coordinate. The galactic enhancement factor f_e is obtained as a function of the galactic longitude l as the following equation:

$$\frac{N^{\rm obs}(l,b)}{N^{\rm exp}(l,b)} = c\left[(1-f_e(l)) + 1.402 f_e(l)\exp\left[-b^2\right]\right] , \tag{1}$$

where $N^{\rm exp}(l,b)$ is an expected arrival direction distribution calculated with taking into account both the array characteristics and the environmental conditions (such as the temperature and pressure variations), b in the galactic latitude and c is a normalization factor. If the arrival direction distribution is completely isotropic, f_e should be zero, and if the distribution is enhanced toward the galactic disk, this factor takes the positive value. In our following analysis, we determined the f_e and c with the least-square fitting to the $N^{\rm obs}/N^{\rm exp}$ distribution.

2. – The result with SAS array

We have observed air showers with SAS array since 1987 whose threshold energy is 30 TeV. The details of this array, the operation and the analysis are already described [2]. We analyzed data accumulated from May 1991 until July 1992, and the number of events remained through the normal selection procedure is 2.7×10^7. The obtained f_e is shown in fig. 1. The significant enhancement can be seen around the galactic longitude from 260°

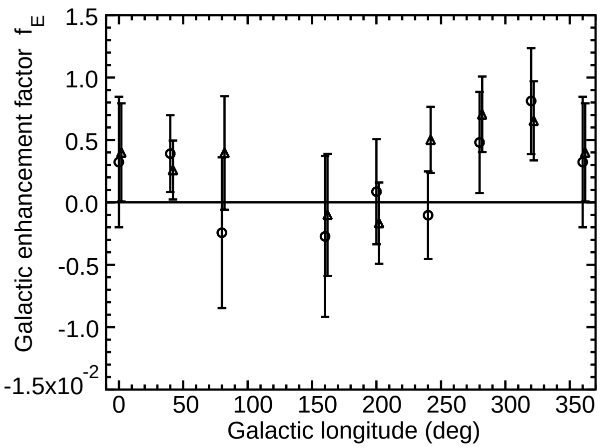

Fig. 2. – The f_e distribution, same as fig. 1, for muon-less air showers (open circle) and for muon-rich air showers (open triangle).

to 340° where includes the direction of Vela SNR. To examine what kind of component of cosmic rays contributes to this enhancement, we classified the observed data into two groups: one is muon-less, *i.e.* the group of the air showers with associated muons less than the corresponding average and the other is muon-rich, that is, the remainder. We analyze these two data sets with the same method, and the results are shown in fig. 2. Each plot of f_e shows almost the same result, so that we cannot conclude that the observed enhancement is due to the primary gamma-rays.

In fig. 3, we present the energy dependence of f_e for the region with the galactic longitude from 260° to 340°. Although the statistics are limited, the enhancement seems to be large with the increasing primary energy. Then, we calculated the propagations of cosmic rays accelerated by the explosion of Vela SNR [5]. The result shows that the enhancement measured with SAS array does not conflict with these simulations if we assume the age of this SNR is 10^5 years, so that Vela SNR is a possible candidate to explain our result.

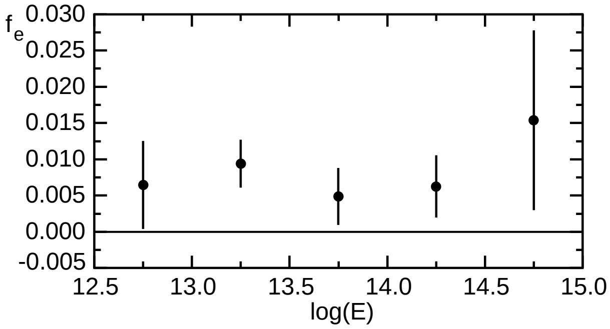

Fig. 3. – The energy dependence of f_e for the enhanced region at the galactic longitude from 260 to 340°.

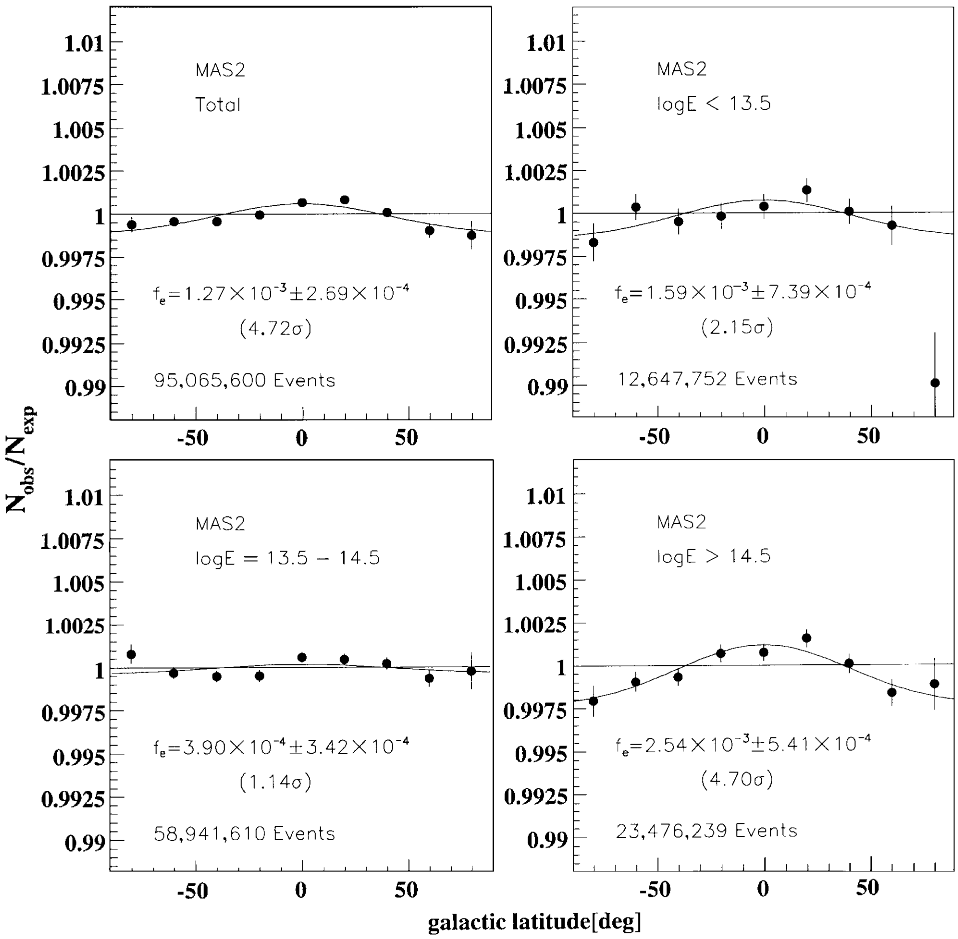

Fig. 4. – The $N^{\text{obs}}/N^{\text{exp}}$ for all galactic longitude measured with MAS2 for whole energy range (upper left) and 3 different energy ranges. The best-fit curves of eq. (1) are drawn in the plots.

3. – The result with MAS array

The construction of MAS array has 2 phases. In the first phase, we added 12 scintillation detectors to SAS array. This new array, called MAS1, was operated from Dec. 1996 to Sep. 1997. In the second phase, we added more 21 detectors to MAS1 to complete the MAS array. The operation of this array, here called MAS2, was started in 1998. The threshold primary energy of observed air showers is 6×10^{12}eV. The details of the array characteristics have been described elsewhere in these proceedings [3].

After the event selection, 1.5×10^8 events are used in studying the galactic-disk enhancement of the arrival direction distribution. The $N^{\text{obs}}/N^{\text{exp}}$ for whole galactic longitude measured with MAS2 is plotted in fig. 4. In this figure, the plot shows small but positive enhancement. Moreover among the 3 data sets classified with primary energies, that for highest energies ($E > 10^{14.5}$ eV) shows the most significant positive enhancement. This energy dependence is the same as the results with SAS array.

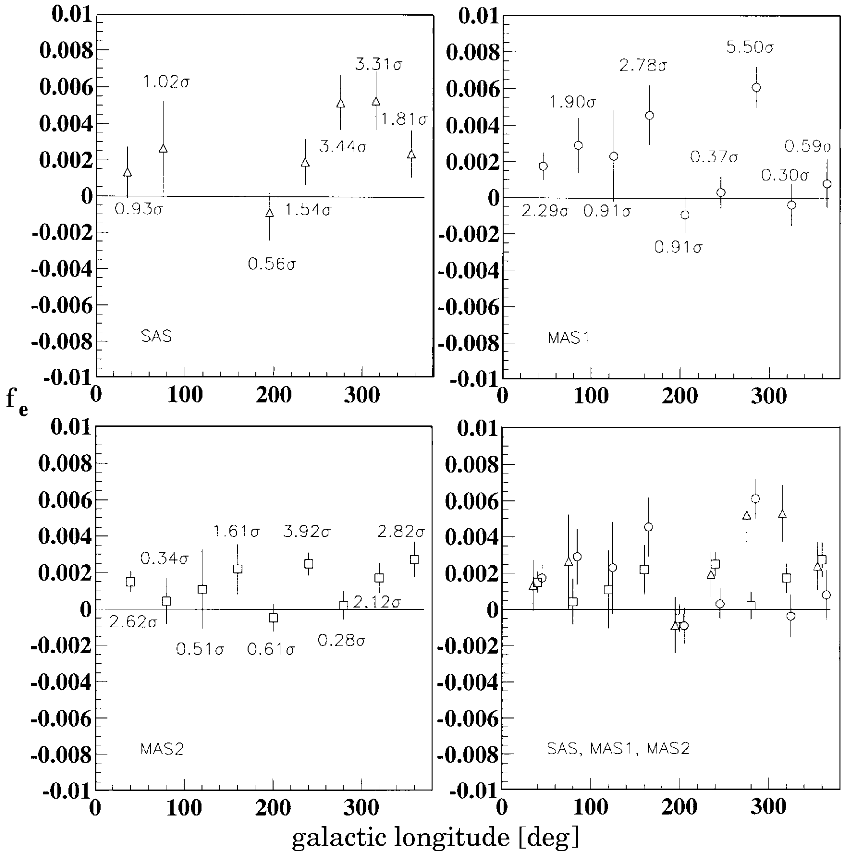

Fig. 5. – The f_e distribution, same as fig. 1, for the data observed with SAS (open triangle), with MAS1 (open circle) and with MAS2 (open square) array.

In fig. 5, we compare three f_e's measured with SAS, MAS1 and MAS2 independently. Each error in the figure is standard deviation σ obtained through the least-square fitting. The value attached to each point is estimated as f_e/σ, and is significant of the enhancement. In the plot for SAS and MAS1 we can see the significant positive f_e, *i.e.* the significant enhancement around the region of the galactic longitude from 270 to 300°. However, there is no significant region in the plot for MAS2, so that at present we are allowed safely to say that cosmic rays are concentrated toward the galactic plane weakly rather than toward particular regions which include a nearby cosmic ray source. The excess around 240° in the galactic longitude in MAS2 data seems to be significant. However, it is not possible to conclude that this excess is significant, because at Mt. Chacaltaya we cannot measure cosmic rays coming from the whole galactic latitude for this region of the galactic longitude.

4. – Conclusion

We observed the enhancement of the cosmic rays arriving from the galactic disk with the galactic longitude from 270° to 330° with SAS array, where Vela SNR is included.

From our analysis on muons associated with the observed air showers, we cannot conclude that this enhancement is due to the primary gamma rays. If this is due to primary nuclear component, the enhancement can be explained with cosmic ray flow from a nearby SNR. The result of the new array shows the weak enhancement from all the directions toward the galactic plane rather than the particular region. The difference in the results of SAS and MAS2 might be attributed to the energy dependence of the enhancement and the difference of the threshold energies of the arrays, or time variation of the galactic magnetic field structure around the earth. The total observation time of the MAS2 is about 5 months at this moment, so that we will accumulate more data to justify these results.

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