

A Possible Observation of Solar Neutrons in Association with November 28th, 1998 Flare

T. Hoshida¹, Y. Matsubara¹, Y. Muraki¹, H. Tsuchiya¹, K. Fujiki¹, S. Masuda¹, K. Izu², Y. Katayose², M. Ohnishi², T. Yuda², L.K. Ding³, A.X. Huo³, H. Lu³, S.L. Lu³, G.X. Luo³, J.R. Ren³, Z.Z. Shi³, Y.H. Tan³, H. Wang³, X.W. Xu³, C.S. Zhang³, H.M. Zhang³, J.L. Zhang³, M. Amenomori⁴, S. Ayabe⁵, P.Y. Cao⁶, Danzengluobu⁷, Z.Y. Fen⁸, Y. Fu⁶, H.W. Guo⁶, M. He⁶, K. Hibino⁹, N. Hotta¹⁰, Q. Huang⁸, A. Ishii⁵, H.Y. Jia⁸, F. Kajino¹¹, K. Kasahara¹², Labaciren⁷, J.Y. Li⁶, X.R. Meng⁷, K. Mizutani⁵, J. Mu¹³, H. Nanjo⁴, M. Nishizawa¹⁴, I. Ohta¹⁰, S. Okubo⁵, T. Ouchi⁹, S. Ozawa⁵, T. Saito¹⁵, M. Sakata¹¹, T. Sasaki¹¹, M. Shibata¹⁶, A. Shiomi⁵, T. Shirai⁹, H. Sugimoto¹⁷, K. Taira¹⁷, N. Tateyama⁹, S. Torii⁹, T. Utsugi⁵, C.R. Wang⁶, P.X.W. Wang¹³, Y. Yamamoto¹¹, G.C. Yu⁸, A.F. Yuan⁷, N.J. Zhang⁶, X.Y. Zhang⁶, Zhaxisangzhu⁷, Zhaxiciren⁷, W.D. Zhou¹³

¹*Solar-Terrestrial Environment Laboratory, Nagoya University, Nagoya, 464-8601, Japan*

²*Institute for Cosmic Ray Research, The University of Tokyo, Tanashi, 188-8502, Japan*

³*Institute of High Energy Physics, Academia Sinica, Beijing, 100039, China*

⁴*Department of Physics, Hirosaki University, Hirosaki, 036-8501, Japan*

⁵*Department of Physics, Saitama University, Urawa, 338-8570, Japan*

⁶*Department of Physics, Shandong University, Jinan, 250100, China*

⁷*Department of Mathematics and Physics, Tibet University, Lhasa, 850000, China*

⁸*Department of Physics, South West Jiaotong University, Chengdu, 610031, China*

⁹*Faculty of Engineering, Kanagawa University, Yokohama, 221-8686, Japan*

¹⁰*Faculty of Education, Utsunomiya University, Utsunomiya, 321-8505, Japan*

¹¹*Department of Physics, Konan University, Kobe, 658-8501, Japan*

¹²*Faculty of Systems Engineering, Shibaura Institute of Technology, Omiya, 330-8570, Japan*

¹³*Department of Physics, Yunnan University, Kunming, 650091, China*

¹⁴*National Center for Science Information Systems, Tokyo, 112-8640, Japan*

¹⁵*Tokyo Metropolitan College of Aeronautical Engineering, Tokyo, 116-0003, Japan*

¹⁶*Faculty of Education, Yokohama National University, Yokohama, 240-8501, Japan*

¹⁷*Shonan Institute of Technology, Fujisawa, 251-8511, Japan*

Abstract

In association with a large solar flare observed at N17E32 of the solar surface in November 28th at 05:36UT, the China-Japan Solar Neutron group possibly observed an arrival of high energy solar neutrons. The statistical significance was $\sim 4\sigma$. In case this event will be established as real one, this becomes the first event of the neutron detection produced by the moderate size of solar flares such as X=3.3. The authors would like to present in the conference a possible acceleration mechanism of ions at the solar surface.

1 Experimental Purpose

It is well known that particles are accelerated beyond 100GeV at the solar surface, though the acceleration mechanism of ions is unclear. We intend to elucidate the mechanism how ions are accelerated into high energy at the solar surface, when flares happen at the Sun, using solar neutrons as a probe. Solar neutrons bring us direct information about the acceleration mechanism of ions, while photons are produced not only by pion decays but also by the bremsstrahlung of electrons. When electrons are abundantly produced, the 2.2MeV line gamma-rays produced by the neutron capture are masked by those photons produced by the

bremstrahlung process. However, the observation of high energy solar neutrons is rare and until now, only five events are reported (Shibata et al., 1993). All those events were detected in association with gigantic flares with $X > 8 \sim 12$.

To increase the chance of solar neutron observations, a new type of solar neutron detector has been installed at high mountains in the world. This new type detectors have a high S/N ratio in comparison with traditional neutron monitors. As a part of the worldwide network of ground based neutron telescopes, a new solar neutron telescope was constructed in September of 1998 at Yangbating (4300m a.s.l.) in Tibet. The detector consists of 9m^2 scintillation counters with 40cm thickness and proportional counters which can determine the arrival direction of neutrons. The 3.6m^3 scintillator block is completely covered by the anti-counters (proportional counters). Details of this telescope were reported in the paper of this conference (Katayose et al., 1999).

2 The November 23rd event of 1998

Three large solar flares were consecutively observed in November 22nd, 23rd and 28th of 1998. At that time, the Sun was observed at the zenith angle of 50 degrees, and respective local time at Yangbajing was near noon. Therefore we have analyzed the data and examined whether our telescope detected solar neutrons or not. No signal was found for the Nov. 22nd flare, but positive excesses were observed for 23rd and 28th flares. For the event of November 23rd, the statistical significance of the excess was at the level of 3.4σ . The statistical significances of Ch.1 ($>40 \text{ MeV}$), Ch2 ($>80 \text{ MeV}$), Ch3 ($>120 \text{ MeV}$), and Ch4 ($>160 \text{ MeV}$) are 3.4, 2.9, 2.7 and 1.7σ respectively (Fig. 1).

According to the Nobeyama radioheliograph, the increase of the radio intensity was seen from $6^{\text{h}}32^{\text{m}}$ UT. A rapid increase of the radio intensity was observed at $6^{\text{h}}34^{\text{m}}$ UT. The peak intensity was reported at $6^{\text{h}}35^{\text{m}}30^{\text{s}}$ UT. The GOES satellite tells us the peak time was $6^{\text{h}}53^{\text{m}}$ UT. We have assumed the acceleration time of ions at $6^{\text{h}}33^{\text{m}}30^{\text{s}}$ UT, which corresponds to the most rapid increase time of the radio intensity. The vertical solid line in Fig. 1 surely corresponds to this time.

Unfortunately, the Yohkoh satellite and CGRO satellite were just in the shadow of the Earth. So we cannot compare details of the time profile with theirs. Since these events were real, the neutron telescopes newly installed in the world give rise to very fruitful results in forthcoming observations. The Riken neutron monitor was recently transferred to Tibet. It has an area of 28m^2 and also observed an excess at about 3.5σ level (Kohno & Miyasaka, 1999). It is interesting to note that the 28m^2 Riken neutron monitor shows the same level positive excess as the 9m^2 neutron telescope. One can estimate the S/N ratio of our new telescope by this number.

In conclusion the Tibet solar neutron telescope possibly observed solar neutrons in association with solar flare of November 23rd with low X-class flare such as $X = 2.2$.

3 The November 28th event of 1998

A few days later, again a large flare was observed at the Sun. The meridian passage of the Sun was again above Tibet. The GOES satellite tells us the peak time of the flare was $6^{\text{h}}09^{\text{m}}$ UT about. In this event, the Nobeyama radio heliograph, Yohkoh satellite and CGRO satellite were all successfully observing. No strong line gamma-rays were detected by the Gamma-Ray

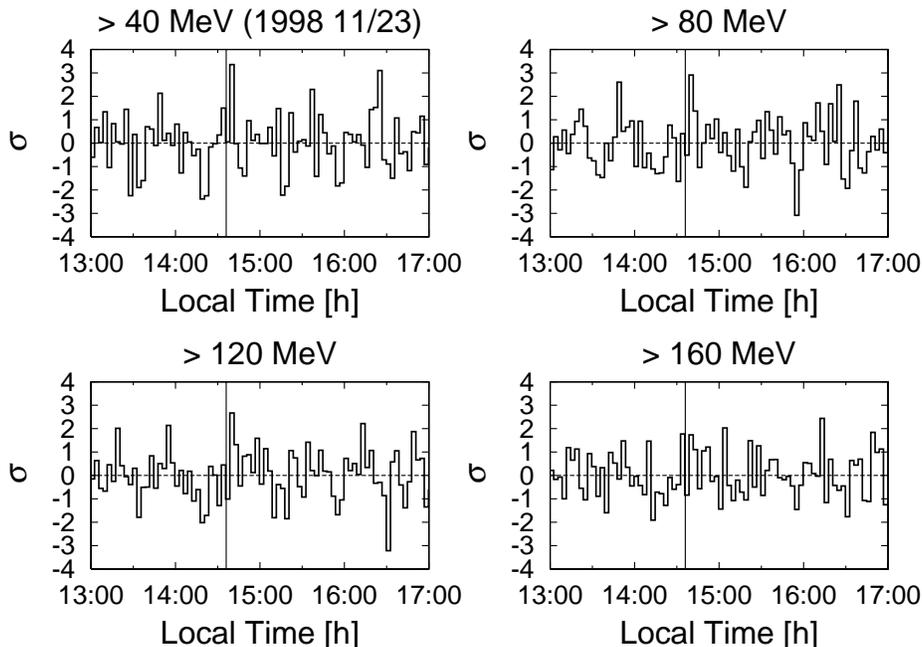


Figure 1: The statistical significance of the counting rate of solar neutron detector. Horizontal-axis and vertical-axis represent the local time and the significance respectively. The vertical solid line in the graphs shows the acceleration time of ions which we assumed at $6^h33^m30^s$ UT or $14^h33^m30^s$ of the local time.

Spectrometer on board Yokoh(Yoshimori,1999). The Yokoh Soft X-ray Telescope shows quite complex loop structures of the solar surface. A clear magnetic field polarization was seen by the Nobeyama radioheliograph. A clear magnetic sharing was also observed by Mitaka magnetograph(Sakurai,1999). However the Riken neutron monitor detected a minor excess (1.7σ) at the corresponding time(Kohno & Miyasaka,1999).

At our solar neutron telescope, a channel (>120 MeV) indicated 1.8σ level enhancement. The statistical significance is not so clear. Therefore we compared the signals coming from the south direction with the north direction. The data coming from the acceptance ± 23.5 degrees in the east-west direction were used for the data analysis. Towards the north-south direction, we compared the data between 20.5 and 28.6 degrees in acceptance.

As shown in Fig. 2b, a sharp enhancement is seen in the south direction, on the contrary, no enhancement in the north direction(Fig. 2a). The enhancement of the south direction suggests us that the excess was produced by neutrons from the Sun. The statistical significance was 4.5σ , but the bottom counter counts twice sometimes in our method, so that the actual significance of the excess should be reduced slightly. Then it turns out to be 3.5σ .

The time profile of this event was examined by a Monte Carlo simulation. If we assume that neutrons were produced with a hard spectrum, the ten seconds time profile of this event can be explained well. More detail results will be shown in the conference.

4 Summary and Discussions

By a newly installed Tibet neutron telescope,

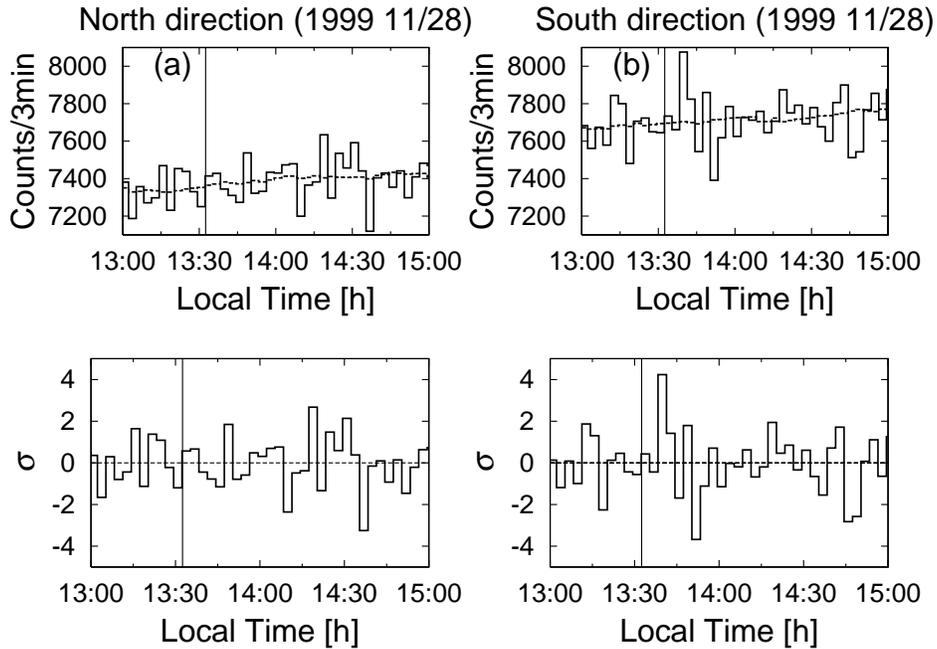


Figure 2: The raw data (top panels) and their statistical significances (bottom panels) for November 28th 1998 flare. The statistical significance from the south direction shows a 4σ level enhancement. The vertical solid line in the graphs represents the acceleration time of ions which we assumed at $5^h32^m30^s$ UT or $13^h32^m30^s$ of the local time.

- (1) solar neutrons are detected. If this was real,
- (2) this is the first evidence that solar neutrons are detected at large flares such as $X=2\sim3$ (less than 8).
- (3) The new type of solar neutron detector demonstrates very high sensitivity in comparison with traditional neutron monitors.
- (4) To confirm present prediction, we must finish our Monte Carlo simulation, taking into account the side neutron showers. This Monte Carlo is necessary to explain why neutrons are weakly detected by the lowest channel of our telescope and also by the Riken neutron monitor.

References

- Katayose, Y., et al. 1999, Proc. 26th ICRC (Utah,1999), SH 1.3.07
 Kohno, T. & Miyasaka H. 1999, Proc. Solar Neutron Symposium (Nagoya),
 66-72 (in Japanese)
 Sakurai, T. 1999, Proc. Solar Neutron Symposium (Nagoya), 36-49(in Japanese)
 Shibata, S., et al. 1993, Proc. 23rd ICRC (Calgary,1993), 3, 95
 Yoshimori, Y. 1999, Proc. Solar Neutron Symposium (Nagoya), 29-35 (in Japanese)