Energy spectrum for the solar neutron event of September 7 2005, derived from the SNT at Sierra Negra

L.X. GONZÁLEZ[1], J. F. VALDÉS-GALICIA [1], A. HURTADO[1], O. MUSALEM[1], Y. MURAKI[2], T. SAKO[2], K. WATANABE[3], Y. MATSUBARA[2], S. SHIBATA[4], T. SAKAI[5], H. TSUJIHARA[2],
[1] *Departamento de investigaciones Solares y Planetarias, Instituto de Geofísica, UNAM 04510, México, D.F., México*
[2] *Solar-Terrestrial Environment Laboratory, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8601, Japan*
[3] *Space Sciences Laboratory University of California, Berkeley, US*
[4] *College of Engineering, Chubu University, Kasugai, Aichi 487-8501, Japan*
[5] *College of Industrial Technologies, Nihon University, 2-11-1, Shinei, Narashino, Chiba 275-0005, Japan*

xavier@geofisica.unam.mx

Abstract: The Solar Neutron Telescope (SNT) at Mt. Sierra Negra in Mexico (19.0°N, 97.3°W) is taking data since June of 2004. A solar neutron event was registered by this SNT, associated with the flare of September 7 of 2005, at the minimum phase of solar cycle 23. In this work we calculate the energy spectrum for this solar neutron event, using the attenuation model by Dorman & Valdés-Galicia [1], and the detector efficiency calculation of Valdés-Galicia [2].

Introduction

The solar neutron event of September 7 2005, associated with an X17 solar flare was the first event registered by the SNT at Mt. Sierra Negra. Furthermore, it was registered by the Neutron Monitor (NM) in Mexico City, the Chacaltaya's NM and SNT. By using the method described in Watanabe et al. [3], Sako, et. al. [4] calculated the energy spectrum of neutrons at the Sun, which was fitted by a power law as 6.1 x 10^{27} (E/100 MeV)$^{-3.8}$ MeV^{-1}. They used data from NM on Chacaltaya, the Shibata program for atmospheric attenuation [5] and the efficiency of the NM calculated by Clemm & Dorman [6]. In this paper we present an alternative spectrum for this solar neutron event, using different models of attenuation and detector efficiency.

Observations

An X17 solar flare occurred on September 7 2005 was registered by *GOES* satellite.

The soft-X-ray emission started at 17:17 UT, reached its maximum at 17:40 UT, and decayed to half-maximum at 18:03 UT. This flare was classified as an East limb flare (S06°, E89°), and it occurred in AR 10808. The *GOES* satellite did not detect a significant increase in charged particles (<0.1 particles s^{-1} cm^{-2} sr^{-1} above 100 MeV). Teresawa, et al. [7] obtained hard X-ray data of the *Geotail*, showing that the >50 keV X-ray emission peaked at 17:36:40 UT (Figure 1).

At the time of maximum X-ray emission detected by *GOES* (17:40 UT), the SNT at Mt. Sierra Negra was suitable place to observe solar neutrons. The solar zenith angle was 17.5°, and the air mass in the line of sight to the Sun was 603 g cm^{-2}.

We may assume that the ion acceleration occurred at the same time as the line γ-rays were emitted, although the main component of these γ-rays is bremsstrahlung, and that solar neutrons were also produced at the same time [8].

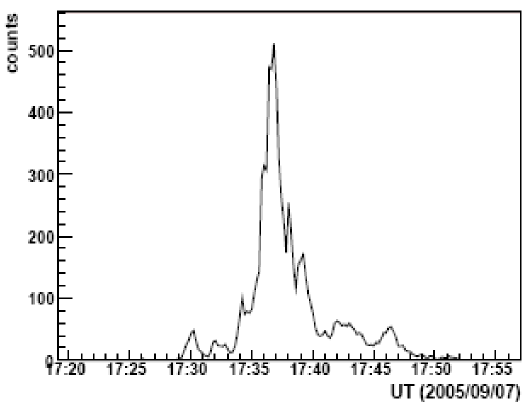

Figure 1. Hard X-ray time profile observed by *Geotail* satellite on 2005 September 7. The maximum emission of X-rays was at 17:36:40 UT.

The Sierra Negra SNT can discriminate four different energy thresholds, which correspond to energy deposit of >30, >60, >90, and >120 MeV [9].

Figure 2 show the two minutes counting rates observed by our SNT on September 7, 2005.

Analysis Result

In order to determine the energy spectrum of solar neutrons during this event, we use 3 minutes average data. We determine the neutron energy by using the time of flight method, assuming that all the solar neutrons were produced at 17:36 UT, the peak time of the intense emission of high energy γ-rays observed by *Geotail* as shown in Figure 1.

To derive the energy spectrum of neutrons at the solar surface, we calculated the survival probability of neutrons between the Sun and the Earth, the attenuation of solar neutrons passing through the Earth's atmosphere using the model by Dorman & Valdés-Galicia [1], and the detection efficiency of the SNT by Valdés-Galicia [2].

Using these results, we calculated the energy spectrum of solar neutrons for the flare of September 7, 2005. The spectrum is shown in Figure 3.

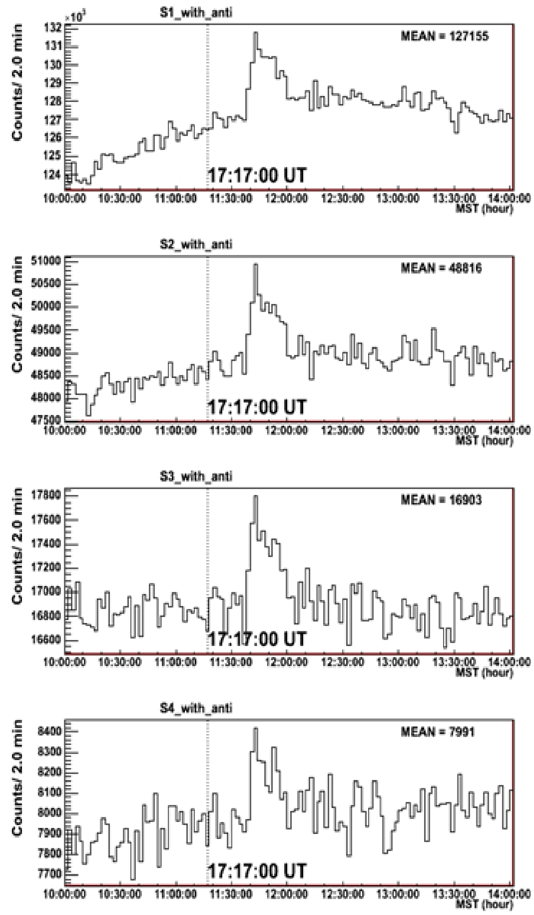

Figure 2. Two minutes averages of the counting rate observed by SNT at Sierra Negra. The time is in local time, which corresponds to six hours less than universal time. S1_with_anti, S2_with_anti, S3_with_anti, and S4_with_anti, correspond to deposit energy >30, >60, >90, and >120 MeV, respectively. 17:17:00 is the time of beginning of solar flare.

By fitting these data points with a power law, the energy spectrum of solar neutrons was obtained. The fitting region is chosen as 100MeV and above, because there the errors from neutron attenuation in the Earth's atmosphere are small [8]. The energy spectrum is well fitted by a power law as:

$$5.3 \times 10^{27} \, (E/100\text{MeV})^{-3.96} \, \text{MeV}^{-1} \, \text{sr}^{-1}$$

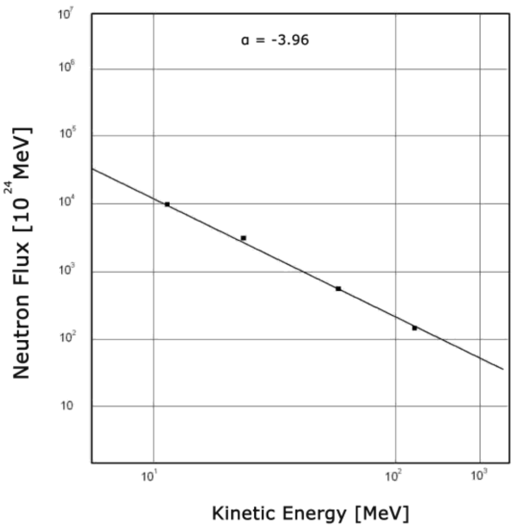

Figure 3. The energy spectrum of solar neutrons for the flare of September 7 2005.

Summary

The energy spectrum of the solar neutrons detected by SNT at Sierra Negra for September 7 2005 event is an independent analysis that gives a quite consistent result comparatively with the spectrum calculated by Sako, et al. [4]. They used data from the neutron monitor (NM) at Chacaltaya, Bolivia, the Shibata program for atmospheric attenuation [5] and the detector efficiency by Clem & Dorman [6].

Acknowledgments

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References

[1] Dorman & Valdés-Galicia J. Geophys. Res. 495. 1999.
[2] Valdés-Galicia, J.F., et al. Nucl. Inst. Meth., A535, 656, 2004.
[3] Watanabe, K., et al. ApJ, 592, 590, 2003.
[4] Sako T., et al., The Astrophysical Journal, 651: L69-L72, 2006.
[5] Shibata, S. J. Geophys. Res., 99, 6651, 1994.
[6] Clem, J. M. & Dorman, L. I. Space Sci. Rev., 93, 335, 2000.
[7] Teresawa, T., et al. Nature, 434, 1110, 2005.
[8] Watanabe, K., et al. 29th International Cosmic Ray Conference Pune (2005) **00**, 101–106
[9] Valdés-Galicia, J.F., et al., Nucl. Instrum. Methods Phys. Res. A, 535, 656, 2004.