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Highly significant detection of solar neutrons on 2005 September 7

K. Watanabe [a,*], T. Sako [b], Y. Muraki [b], Y. Matsubara [b], T. Sakai [c], S. Shibata [d], J.F. Valdés-Galicia [e], L.X. González [e], A. Hurtado [e], O. Musalem [e], P. Miranda [f], N. Martinic [f], R. Ticona [f], A. Velarde [f], F. Kakimoto [g], S. Ogio [h], Y. Tsunesada [g], H. Tokuno [g], Y.T. Tanaka [i], I. Yoshikawa [i], T. Terasawa [i], Y. Saito [j], T. Mukai [j], M. Gros [k]

[a] *Space Sciences Laboratory, University of California, Berkeley, 7 Gauss Way 7450, Berkeley, CA 94720, USA*
[b] *Solar-Terrestrial Environment Laboratory, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8601, Japan*
[c] *College of Industrial Technologies, Nihon University, 2-11-1, Shinei, Narashino, Chiba 275-0005, Japan*
[d] *College of Engineering, Chubu University, Kasugai, Aichi 487-8501, Japan*
[e] *Instituto de Geofísica, Universidad National Autónoma de México, Ciudad Universitaria, Coyoacán D.F. 04510, México*
[f] *Instituto Investigaciones Fisicas, Universidad Mayor de San Andrés, La Paz, Bolivia*
[g] *Department of Physics, Tokyo Institute of Technology, Meguro-ku, Tokyo 152-8551, Japan*
[h] *Graduate School of Science, Osaka City University, Osaka 558-8585, Japan*
[i] *Department of Earth and Planetary Science, University of Tokyo, Tokyo 113-0033, Japan*
[j] *ISAS/JAXA, Sagamihara 229-8510, Japan*
[k] *DSM/DAPNIA/SAp, CEA Saclay, 91191 Gif-sur-Yvette, France*

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Abstract

We have successfully detected solar neutrons at ground level in association with the X17.0 solar flare that occurred on 2005 September 7. Observations were made with the solar neutron telescopes and neutron monitors located in Bolivia and Mexico. In this flare, large fluxes of hard X-rays and γ-rays were observed by the *GEOTAIL* and the *INTEGRAL* satellites. The *INTEGRAL* observations include the 4.4 MeV line γ-rays of ^{12}C. The data suggest that solar neutrons were produced at the same time as these hard electromagnetic radiations. We have however found an apparent discrepancy between the observed and the expected time profiles. This fact suggests a possible extended neutron emission.

Keywords: Solar flare; Solar X-rays and γ-rays; Solar particle event; Cosmic rays

1. Introduction

Solar neutrons are very useful in order to investigate ion acceleration mechanisms in a solar flare. In order to learn about the acceleration mechanism of ions in solar flares, it would be best to observe the accelerated ions directly. However, ions are deflected by magnetic fields at the acceleration site and by interplanetary magnetic fields on the way to the Earth. Their characteristics are modified by not only magnetic fields, but also interactions with plasma waves and shocks. So, when they arrive at the Earth, exact information on the acceleration time, direction and energy have already been lost. On the other hand, solar neutrons produced at the solar flare site arrive at the Earth, and retain information on the acceleration, because they are not affected by any magnetic fields along their path. By observing solar neutrons, we can determine the energy spectrum of the solar neutrons and accelerated ions, and the production time of the solar neutrons.

Solar neutrons are observed by neutron monitors and solar neutron telescopes on the ground. Neutron monitors were originally intended for continuous recording of the cosmic ray flux, and are located at more than 50 stations

* Corresponding author. Tel.: +1 510 642 9557.
E-mail address: kwatana@ssl.berkeley.edu (K. Watanabe).

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around the world. However, they cannot measure the energy of solar neutrons except by the time-of-flight (TOF) method. On the other hand, a solar neutron telescope is a specialized detector designed to observe solar neutrons in association with solar flares. It can measure the energy and the direction of incoming neutrons. Such telescopes are now located at seven stations. These detectors make up an international network of solar neutron observations, with around-the-clock observing. By using these detectors, a few solar neutron events have been observed in solar cycle 23 (e.g. Watanabe et al., 2003, 2006; Bieber et al., 2005). These events were invariably observed in association with strong γ-ray emissions, and solar neutron emission can be explain by assuming that solar neutrons were emitted at about the same time at the γ-ray emissions (Watanabe et al., 2005).

On 2005 September 7, in association with an X17 flare, a large solar neutron event were observed by the ground-based detectors. In this paper, we report this solar neutron event and describe analysis results.

2. Solar neutron event on 2005 September 7

In 2005 September, an extensive active region (NOAA 10808) produced 10 X-class solar flares. Among them, the first (17:17 UT on 2005 September 7) was the most energetic event, and had a soft X-ray magnitude of X17. This event was at the East limb (S06° E89°).

Unfortunately, RHESSI was both in the SAA and on the night side of the Earth during this flare. However, the *GEOTAIL* satellite successfully observed solar hard X-rays, and a strong emission of γ-rays was also observed by the *INTEGRAL* satellite.

Fig. 1 shows the hard X-ray data from *GEOTAIL*, and the γ-ray data from *INTEGRAL*. The γ-ray spectrum (Fig. 1(b)) clearly shows the ^{12}C γ-ray line. It does not show the 2.2 MeV neutron-capture line, but this is consistent with the limb location. The time profile of γ-rays more than 1 MeV (Fig. 1(c)) shows the accelerated electrons, and the time profile around the 4.4 MeV γ-ray line (Fig. 1(d)) shows accelerated ions. They have very similar time profiles, peaking at 17:36:40 UT. From these data, we can assume that solar neutrons were produced for a few minutes around 17:36:40 UT.

At the time of the X17 flare, the Sun was located over South America. Fig. 2 shows the position of the Sun on the world map. At this time, detectors which are located in Mexico and Bolivia were in good places for observing solar neutrons. The best place was at Sierra Negra in Mexico (262°.7E, 19°.0N; 4580 m above sea level [a.s.l.]), at this time, the zenith angle of the Sun was 17.5°, and the air mass for the line of sight to the Sun was about

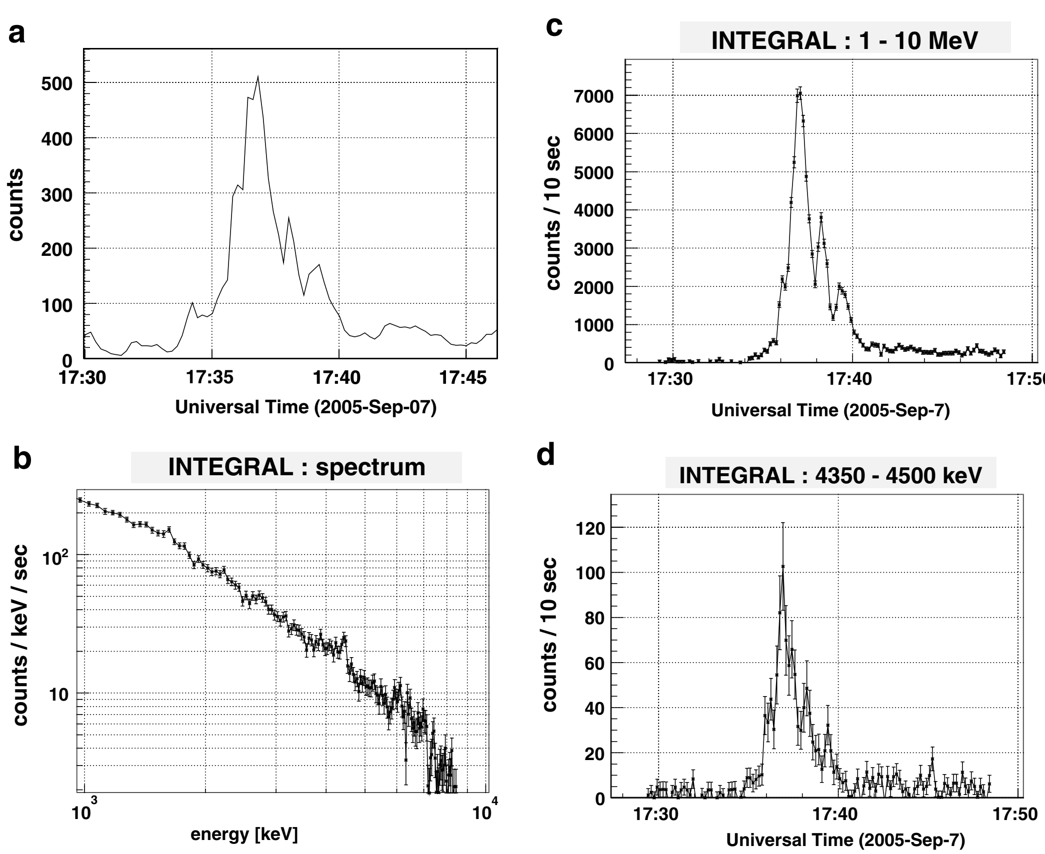

Fig. 1. (a) The time profile of hard X-rays (>50 keV) observed by the *GEOTAIL* satellite. (b) The energy spectrum of γ-rays observed by the *INTEGRAL* satellite. The γ-ray time profiles for the energy range between 1 and 10 MeV (c), and around 4.4 MeV (d) observed by the *INTEGRAL* satellite on 2005 September 7.