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Solar neutron events in association with large solar flares in November 2003

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Abstract

The Sun was intensely active from late October to the beginning of November 2003. A series of 11 X class solar flares occurred in NOAA regions 484, 486 and 488. Unique among this series of flares were those occurring on November 2 and 4 in which solar neutrons were observed by the ground based neutron monitors located at Mt. Chacaltaya, Bolivia and Haleakala, Hawaii, respectively. In these flares, intense emission of hard X-rays and γ-rays have been observed by the satellites. It seems that production of solar neutrons coincided with the production of the hard electromagnetic radiations of these two flares.

Keywords: Solar particle events; Solar neutrons; Solar γ-ray

1. Introduction

Solar neutrons are essential in the investigation of ion acceleration mechanisms in a solar flare. Solar neutrons are produced in association with solar flares by the interaction of the accelerated ions with the solar atmosphere. They arrive at the earth together with the 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 which is nearly the same as the acceleration time of the ions.

Solar neutrons are observed by neutron monitors and solar neutron telescopes on the ground. Neutron monitors are continuous recorders of cosmic ray intensity and are located at more than 50 stations worldwide. However, they can only measure the energy of solar neutrons using the time of flight method. Solar neutron telescopes, on the other hand, are specialized detectors designed to observe solar neutrons in association with solar flares. They can measure the energy and the

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Table 1
List of X class solar flares observed by the GOES satellite from late October to the beginning of November 2003

Date	GOES start time (UT)	GOES soft X-ray class	Active region NOAA No.	Active region location
October 19, 2003	16:29	X1.1	484	N08 E58
October 23, 2003	08:19	X5.4	486	S21 E88
October 23, 2003	19:50	X1.1	486	S17 E84
October 26, 2003	05:57	X1.2	486	S15 E44
October 26, 2003	17:21	X1.2	484	N02 W38
October 28, 2003	09:51	X17.2	486	S16 E08
October 29, 2003	20:37	X10.0	486	S15 W02
November 2, 2003	17:03	X8.3	486	S14 W56
November 3, 2003	01:09	X2.7	488	N10 W83
November 3, 2003	09:43	X3.9	488	N08 W77
November 4, 2003	19:29	X28	486	S19 W83

direction of incoming neutrons. Such telescopes are now located in seven stations around the world. These detectors make up an international network of solar neutron observation. Using this international network of neutron monitors and solar neutron telescopes, solar neutrons were detected in solar cycle 23 (Watanabe et al., 2003a,b; Sako et al., 2003).

The Sun was intensely active from late October to the beginning of November 2003. During this period, three extensive active regions (NOAA Nos. 484, 486 and 488) appeared on the Sun and produced 11 X class solar flares (Table 1). Among them, on November 2 and 4, two notable solar neutron events occurred simultaneously in association with two solar flares. Neutrons were detected by the neutron monitors located at Mt. Chacaltaya, Bolivia and Haleakala, Hawaii, respectively.

In this paper, we report these solar neutron events and describe the analysis results.

2. Solar neutron event on November 2, 2003

At 17:03 UT on November 2, 2003, an X8.3 class solar flare occurred in NOAA active region 486. The start time was 17:03 UT and the flux reached its maximum at 17:25 UT, 22 min after the onset of the solar flare. During this time, large amounts of hard X-ray and γ-ray emissions were observed by the RHESSI satellite.

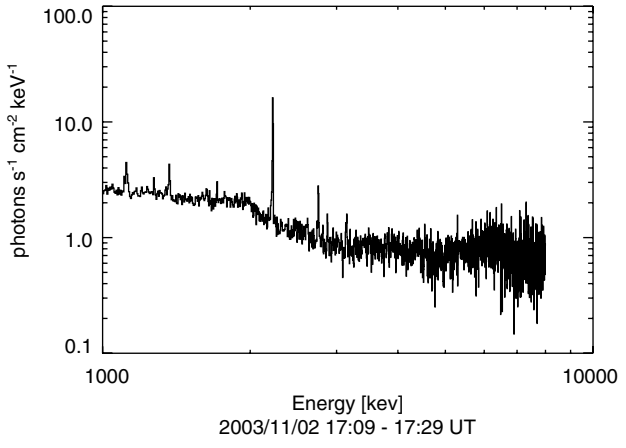

Fig. 1. γ-ray spectrum observed by the RHESSI satellite on November 2, 2003. 2.223 MeV neutron capture γ-ray line is clearly seen.

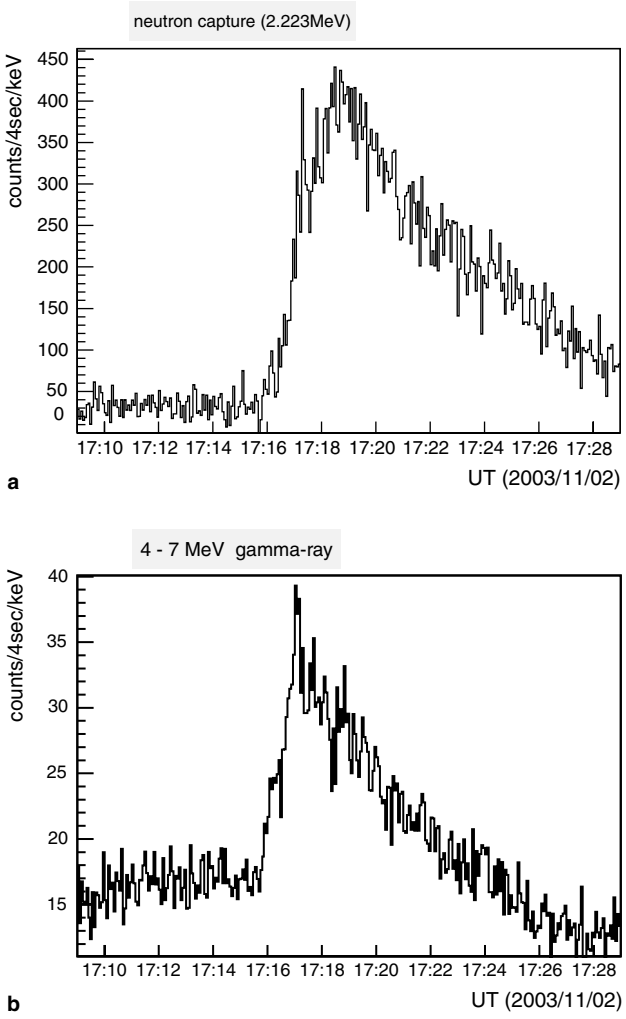

Fig. 2. 2.223 and 4–7 MeV γ-ray time profiles observed by the RHESSI satellite on November 2, 2003. The peak time of the 2.223 MeV γ-ray delay about 100 s from that of the 4–7 MeV γ-ray.