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Search for solar neutrons associated with proton flares in solar cycle 23

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Solar neutrons associated with solar proton events have been searched for in solar cycle 23 by using data obtained by the worldwide network of solar neutron telescopes, which are dedicated to observe solar neutrons. No clear evidence of solar neutron events in association with proton events has been found so far, although a systematic analysis for all the proton events in solar cycle 23 is still in progress. The analysis result for the proton event on April 18th 2001, when the ground level enhancement has also been detected, is presented. The solar neutron telescopes at Mt. Norikura and in Tibet also showed similar enhancements of counting rates at the same time, when both detectors are at good positions to observe solar neutrons. These enhancements were also compared with counting rates obtained by other solar neutron telescopes, and it is concluded that they are due to high energy protons of the order 10 GeV. This analysis shows the probability of detecting not only solar neutrons but also very high energy protons by the network of solar neutron telescopes.

1. Introduction

Detecting neutrons associated with solar flares is important for the study of the acceleration mechanism of ions at the flare site because the propagation of neutrons is not affected by magnetic fields. So far, solar neutrons have been searched for and have actually been detected on the ground during solar cycle 22 in association with giant solar flares in soft X-rays, such as X-class flares [1, 2]. It is, however, more natural to search for solar neutrons associated with proton events, sometimes ground level enhancements (GLEs), because in these events it is clear that ions have been accelerated. Solar neutron telescopes, which are dedicated to observe solar neutrons and to measure their energies, have been operating since the beginning of solar cycle 23. Distributed in a worldwide network covering all longitudes they watch the Sun 24 hours a day. In this paper, we report on results of the search for solar neutron events using data obtained by this international network of solar neutron telescopes.

Table 1. List of solar neutron telescopes

Place	Country	longitude (degree)	latitude (degree)	altitude (m)	Area (m^2)	rigidity cutoff (GV)
Norikura	Japan	138 E	36 N	2,770	64	8
Tibet	China	91 E	30 N	4,300	9	13
Aragats	Armenia	44 E	40 N	3,200	4	8
Gornergrat	Switzerland	8 E	46 N	3,135	4	4
Chacaltaya	Bolivia	68 W	16 S	5,250	4	15
Sierra Negra	Mexico	97 W	19 N	4,600	4	8
Mauna Kea	USA	155 W	20 N	4,200	8	8

2. Worldwide Network of Solar Neutron Telescopes

As mentioned in the previous section, we can measure the energy of neutrons by a solar neutron telescope. The prototype of the solar neutron telescope was constructed at Mt. Norikura, Japan in 1990 [3], and was subsequently successful in detecting a solar neutron event on June 4th, 1991 [2]. A network of solar neutron telescopes has been constructed since 1992, starting at Chacaltaya, Bolivia, and was almost completed in 1998, just before the maximum activity phase of solar cycle 23 [4]. Since solar neutron telescopes are dedicated to observe solar neutrons, they are constructed at high mountains near the equator. Therefore the rigidity cutoff for cosmic rays at each station of solar neutron telescope is in general higher than the average cutoff rigidity at neutron monitors. Therefore solar neutron telescopes are good at observing not only solar neutrons, but also higher energy cosmic rays in association with solar flares. A new 4 m^2 solar neutron telescope was added at Mt. Sierra Negra, Mexico, and has been operating since 2004 [5]. Solar neutron telescopes are listed in Table 1.

3. Solar Proton Events on 18th April 2001

3.1 Solar Activity during March and April, 2001

The Sun was active from the end of March until the middle of April in 2001, and 9 X-class flares occurred during this active period. A very intense GLE occurred in association with the X14 flare on April 15 [6, 7]. This X14 flare was caused by the active region 9415 and occurred at 20°S and 85°W, which was therefore almost a limb flare. Three days after the GLE on April 15th, another GLE occurred at around 3 UT on April 18th [6]. Although there was no X-class solar flare associated with this GLE, it is possible this GLE was caused by a gigantic flare which might have been produced by the active region 9415 behind the limb.

3.2 Neutron Monitors and the GOES satellite

In order to investigate the energy dependence of the solar proton flux, the time profiles of GOES protons in different energy channels were compared with the data of the Oulu neutron monitor [8]. The counting rate of protons has a tendency to increase more rapidly when the energy of protons is higher. On the other hand, the rigidity cutoff of the Oulu neutron monitor is 0.8 GV, which means that the energy of protons measured at Oulu is higher than those measured at the GOES satellite. The time profile of the Oulu neutron monitor shows much more rapid increase than those of GOES protons (see Figure 2).

3.3 Solar Neutron Telescopes - Tibet and Norikura

At around 3 UT on April 18, 2001, the Sun was above Norikura and Tibet, where it was therefore possible to observe solar neutrons. Both the Norikura and the Tibet neutron telescopes have anti-counters to veto charged particles, by which we could measure the number of neutrons at the detectors. The 5 minute counting rates of neutron channels at Norikura (>20 MeV) and Tibet (>40 MeV) are shown in Figure 1, and both time profiles are similar at around 3–4 UT. The Norikura detector showed a 0.7 % increase of counting rate in 1 hour, and the detector in Tibet showed a 1.5 % increase. Next, we compared the time profile of 5 minute counting rates of neutrons at Norikura with those of the Oulu neutron monitor and the GOES protons (Figure 2). The counting rate of neutrons at Norikura shows a slower increase than those of charged particles at Oulu and the GOES satellite.

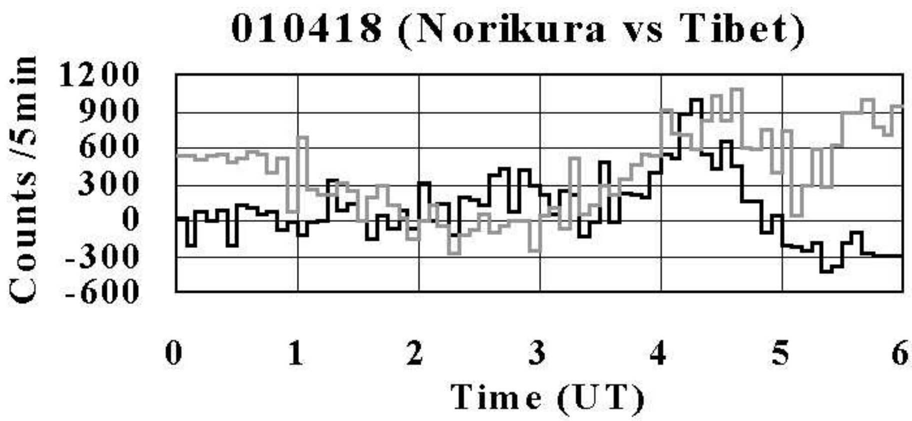

Figure 1. Five minute counting rates of neutron channels at Norikura (>20 MeV; black) and Tibet (>40 MeV; grey) on April 18th, 2001. Both show similar time profiles at around 3 UT. Absolute values are normalized for comparison.

4. Discussions

In case we are observing solar neutrons, it is expected that the counting rates of neutrons should show faster increase than those of protons, because neutrons are not reflected by the interplanetary magnetic field. The observational result in this event is opposite to the expectation, as shown in Figure 2. However, the increase of counting rates of neutron channels at around 3 UT which appears in both the Norikura and the Tibet data, turned out to be common also to the counting rates of the detectors at Gornergrat and Aragats (not shown in Figure 2). For both Gornergrat and Aragats, 3 UT is night time. Therefore this common increase of counting rates should be due to charged particles rather than neutrons. As shown in Table 1, the rigidity cutoffs for protons at these 4 stations are 4–13 GeV. There is therefore a strong indication that protons were accelerated to higher energies than 10 GeV associated with this event.

The analysis of this event is still in progress, and will be presented at the Conference including other events.

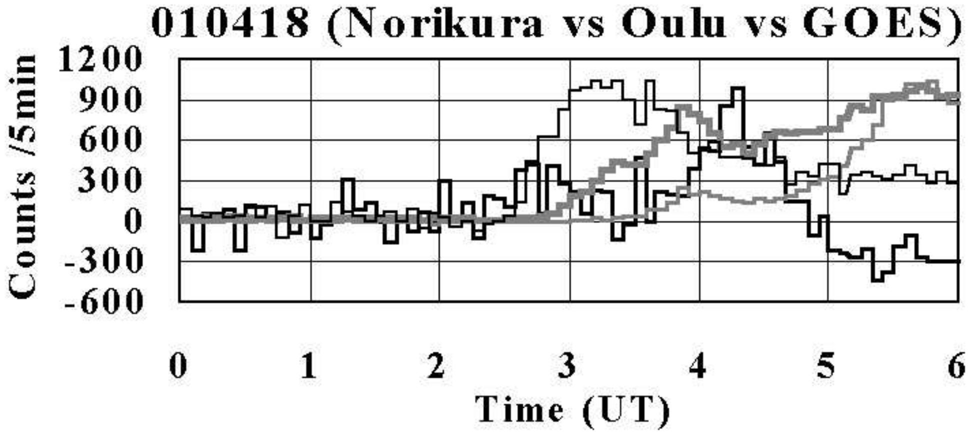

Figure 2. Comparison of 5 minute counting rates on April 18, 2001 obtained by the Norikura solar neutron telescope (thick black line: >20MeV, neutron channel), the Oulu neutron monitor (thin black line), and the GOES proton channel (grey line: thin; 39–82 MeV, thick; 110–500 MeV). Absolute values are normalized for comparison.

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