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Search for solar neutrons associated with series of X-class flares during the declining period of solar cycle 23

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Abstract: Gigantic solar flares exceeding X-class occurred 10 times in September, 2005, and 4 times in December, 2006, although the Sun had already been in the declining phase in solar cycle 23. In this paper, we report on results of the search for solar neutron events associated with these 14 X-class flares, using data obtained by the international network of solar neutron telescopes. There was no clear evidence for detecting solar neutrons within these periods, except for the significant detection of solar neutrons on September 7, 2005.

Introduction

It is important to observe very high energy particles associated with solar flares in order to study the acceleration mechanism of charged particles at the Sun, which will give an important clue to understanding the acceleration of cosmic rays in general. Detecting neutrons is important in this sense because neutrons are not reflected by magnetic fields and keep information on the time when neutrons are emitted at the Sun. Solar neutron telescopes, which are dedicated to observe solar neutrons and to measure their energies, have been in operation since the beginning of solar cycle 23 [1]. They are distributed in the world to cover all longitudes to watch the Sun for 24 hours a day.

It was surprising that Gigantic solar flares exceeding X-class occurred 10 times in September, 2005, because the activity of the Sun had already been in the declining period. More surprisingly, 4 X-class solar flares occurred in December, 2006, when the activity of the Sun was almost at the minimum. It is expected that some of these flares were accompanied by the acceleration of ions, which would be observed as solar neutrons or GLEs on the ground. In this paper, we report on results of the search for solar neutron events associated with these 14 X-class flares, using data obtained by this international network of solar neutron telescopes. Details on the significant detection of solar neutrons on September 7, 2005 [2] are presented by different papers in this Conference [3, 4].

Solar Neutron Telescopes

In order to know the acceleration time of ions at the Sun by detecting solar neutrons at the detector site, it is essential that the detector could measure the energy of neutrons, because neutrons have mass and the time of flight of neutrons from the Sun to the Earth depends on their energies. Every solar neutron telescope in the world-wide network measures the energy of a recoil proton by an incident neutron in the scintillation detector . It is not possible to derive the energy of the neutron correctly from the energy of the recoil proton, unless we know the original direction of the neutron. In the case neutrons come from the Sun, we can infer the energy distribution of neutrons by measuring the energy distribution of recoil protons.

In each detector of the network, counting rates of neutrons are measured every 10 seconds at different threshold energies of recoil protons. In addition, solar neutron telescopes have ability to measure counting rates of neutrons from different directions, by which we can know if the neutrons come from the Sun or not, thus increasing the detection efficiency of solar neutrons [5].

Results

Ten X-class flares occurred at the same active region 10808 in September, 2005. Examination of counting rates at each solar neutron detector for various thereshold energies in the network did not give any significant enhancements associated with these 10 X-class flares except for significant enhancements associated with the X17 flare on September 7, 2005. Four X-class flares in December 2006 also occurred at the one active region 10930 and solar neutron detectors also did not record any signigicant enhancements during these flares. As examples of the analyses, the case for the X-class flare on September 8, 2005, and on December 13, 2006 are shown below.

Search for solar neutrons on September 8, 2005

An X5.4 class flare occurred at 20:52UT on September 8, 2005. The flare was located at S11E74 on the solar surface, which was near the eastern limb of the Sun. Among 7 solar neutron telescopes in the network, the detectors in Mexico and Hawaii were at good positions to observe solar neutrons. The relation between the position of the Sun and solar neutron telescopes is shown in Figure 1. As shown in Figure 1, attenuation of neutrons in the air is almost same for both detecors. Therefore the detection probability of solar neutrons is the same for both detectors if both have the same detection efficiency to neutrons.

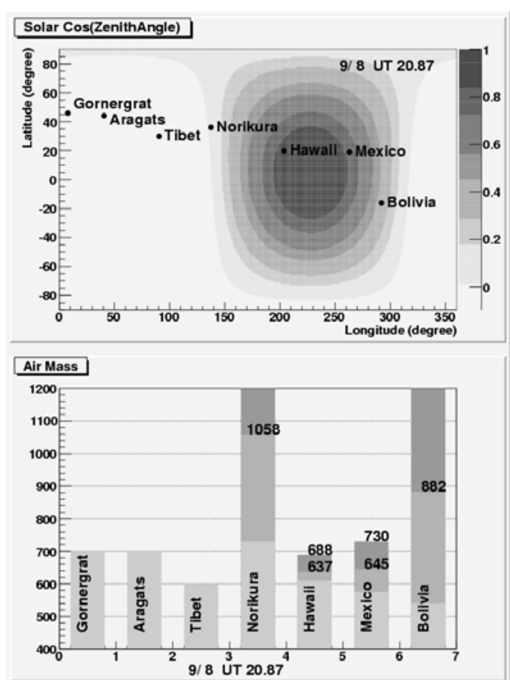

Figure 1: The position of the Sun at 20:52UT on September 8, 2005 and the atmospheric depths for neutrons to reach to each solar neutron detector.

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This situation is quite similar to that in the case of X17 flare on September 7, when the atmospheric depths of neutrons to reach to the detectors in Mexico and Bolivia were almost same.

On the other hand, the locations of X-class flares on September 7 (S06E89) and September 8 are both near the east limb of the Sun. The only difference is the flux of X-rays, and the former case is more intense than the latter case by a factor of only 3. The direction of neutrons emitted at the Sun is almost the same direction as the original charged particles. Therefore if the acceleration of particles to higher energies always occurs at the same place on the solar surface, we can expect the detection of solar neutrons when gigantic flares occur at the same place on the Sun. Moreover it is reasonable to expect the same acceleration mechanism for these two flares because they occurred at the same active region.

Counting rates of neutrons for both detectors at Hawaii and Mexico were compared in the different levels of the energy threshold and different bins of time interval. We could not detect any significant enhancements of counting rates in this detailed analysis.

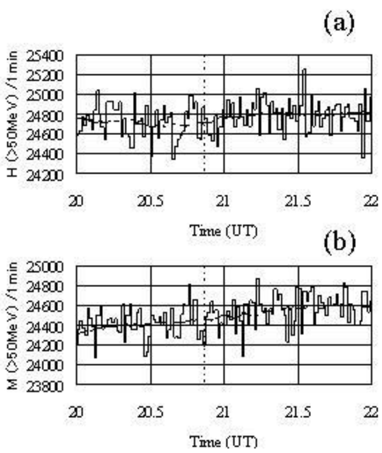

Figure 2: One minute counting rates for neutrons (>50MeV) measured by solar neutron telescopes in Hawaii (a) and Mexico (b). Smooth lines are runnning averages for 60 minutes. The vertical dotted line is the start time of the X-ray flare.

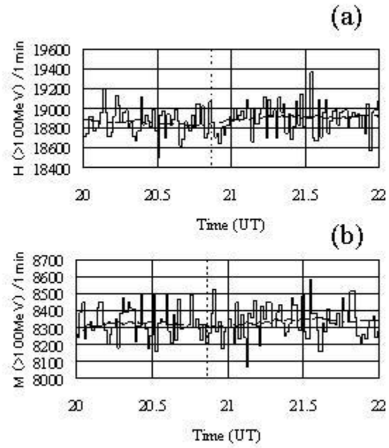

Figure 3: One minute counting rates for neutrons (>100MeV) measured by solar neutron telescopes in Hawaii (a) and Mexico (b). Smooth lines are running averages for 60 minutes. The vertical dotted line is the start time of the X-ray flare.

One minute counting rates measured by both detector are shown in Figure 2 and Figure 3 for different energy thresholds (50 MeV and 100 MeV). There are no significant enhancements of counting rates correlated with the flare.

An X3.4 flare on December 13, 2006

An X3.4 flare occurred at the location of the solar surface S06W24 on December 13, 2006. One of the interesting feature of this flare is that it was accompanied by ground level enhancements (GLE). The solar neutron telescope at Gornergrat in Switzerland also recorded GLE. Every solar neutron telescope records not only neutrons which did not hit veto conters, either scintillation counters or proportional counters, but also charged particles which hit veto counters. Therefore it is possible that one station detects both solar neutrons and GLE.

In the case of the X3.4 flare, the start of the flare was 2:14UT, and the enhancement recorded by the solar neutron telescope at Gornergrat must not be solar neutrons. The station which had a possibility to detect solar neutrons was the solar neutron telescope at Mt. Norikura in Japan. Therefore we compared counting rates measured at Norikura with those at Gornergrat.

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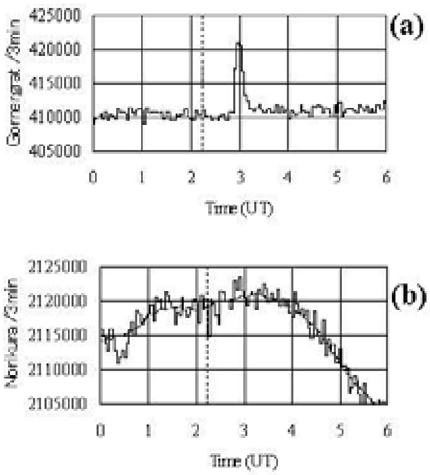

Figure 4: Three minute counting rates measured by the Gornergrat (a) and Norikura (b) solar neutron telescopes on December 13, 2006. The smooth line in (b) is the running average of counting rates for 1 hour. The vertical dotted line shows the start time of the X-ray flare.

Neutrons are expected to come earlier than GLE, but the counting rates in Figure 4 do not show any increase indicating solar neutrons. Although we could not obtain the evidence for the emission of solar neutrons, it is certain that particles were acclerated to high energies associated with this flare, because the cutoff rigidity at Gornergrat is 4.5 GV.

Summary

The results of searching for solar neutron events by using data from solar neutron telescopes were summarized. Solar neutron telescopes are dedicated to observe solar neutrons and distributed in a worldwide network to watch the Sun for 24 hours. The analysis was focused on 14 X-class solar flares which occurred in September 2005 and December 2006. There was no clear evidence for detecting solar neutrons except for one significant detection of solar neutrons.

This network of solar neutron telescope will operate through solar cycle 24 and more fruitful results are expected related with the acceleration of particles on the Sun.

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