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Possible >10GeV Particle Detection in Association with the 28 May 2003 Solar Flare

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We report a short time scale excess observed in the Norikura and Hawaii Solar Neutron Telescopes, the Norikura neutron monitor and the Norikura muon telescope at the beginning of the X3.6 class solar flare occurred on 28 May 2003. Because the direction of the particles measured with the Norikura SNT was toward to the sun, we regard it as a solar neutron signal. To explain the response of different energy channels of the detector, we recognized that consideration of high energy (>10GeV) primary neutrons are necessary. We performed full Monte Carlo calculations of the solar neutron propagation from the sun to the detector and found that high energy neutrons with a hard ($\alpha = 2.5$) spectrum can explain the observed counts of different channels.

1. Introduction

High energy neutrons emitted from the solar surface (solar neutrons) are being monitored long time to study the nature of ion acceleration on the sun. Unlike ions, the path of the neutrons is not bent by magnetic fields. The arrival time profile on the earth therefore reflects the emission/acceleration profile on the sun. On the other hand, since the masses of both ions and neutrons are comparable to their kinetic energies, the observed arrival times disperses according to their energy spectra. Consequently, observed time profile of solar neutrons is a result of degeneracy of emission profile and energy spectrum. To solve this degeneracy, the Solar Neutron Telescope (SNT) is designed and operated as a world wide network [1][2]. Effort to obtain spectrum information from classical neutron monitor is also in progress [3].

In this paper, we present an analysis result of a solar neutron event associated with the 28 May 2003 solar flare. To understand the counting rate of energy dependent channels of SNTs, we performed full Monte Carlo calculations of neutron propagation from the sun to the detectors.

2. Observations

The flare occurred at 0:17 UT on 28 May 2003. The soft X-ray monitored by GOES peaked at 0:27 UT and the peak flux reached at X3.6. Because the orbit of the RHESSI satellite was in the night, no gamma-ray data was obtained. Only weak increase of $>$ 10MeV proton was observed in space after this flare. At the time of the flare onset, Mauna Kea (Hawaii, USA) and Norikura (Japan) are suitable places to observe solar neutrons by SNT. The zenith angles of the sun from the observatories were 26° and 37°, respectively. Column densities of the atmosphere to the direction toward the sun were 676 $\mathrm{g/cm^2}$ and 908 $\mathrm{g/cm^2}$, respectively.

Counting rates of the different type of the detectors are shown in Figure-1. For the Norikura SNT, count of the plastic scintillator (64 m^2 and 20 cm in thickness), which acts as a target of neutron to generate charged particle is plotted (S1_Anti). High energy channel (L4) is also plotted which counts penetrating charged particles, which hits scintillator and 4 successive layers of proportional counters (PRCs) below scintillators. Scintillators are covered by proportional counters and 'antied' data are shown here to enhance signal from neutral particles. In addition, we show counting rates of the muon telescope (U+L) and neutron monitor (NM). U+L records the count of two layers of 36 m^2 thin plastic scintillators. These 4 data were obtained at the same place, the Norikura Observatory (137.5°E, 36.1°N, 2770 m a.s.l.), Institute for Cosmic Ray Research, University of Tokyo. At the bottom of Figure-1, data from the Mauna Kea SNT is shown, which is the channel measuring the count of the plastic scintillator with 8 m^2 and 20 cm thickness. The Mauna Kea SNT is located in the building of the Subaru telescope at Mauna Kea, Hawaii (156.3°W, 19.8°N, 4200 m a.s.l.).

We can find excess counts just before flare onset indicated in the figure. Though each excess is small, the coincidence in time, especially among the different type of detectors and detectors in different place is remarkable.

3. Puzzle of High Energy Channel

As the Norikura SNT can measure the direction of particles when they penetrate 4 layers of PRCs, we mapped the direction at 11:15-11:17 UT. At this time, the sun was to the east from Norikura and we found excess in this direction. This supports our interpretation that we have observed solar neutrons.

Similar SNT events showing asymmetrical excess from the solar direction have been already reported [5] [6]. However, we have been puzzled by these events. Because the excess in the direction channel is produced by relatively high energy particles, comparison with lower energy channel must give us information of the neutron spectrum. Here, we take a ratio L4/S1_Anti as an indicator of the hardness of the incoming particles. Taking the count at 11:15-11:17 UT, observation gives hardness ratio of 0.61 ± 0.40^{stat}, nearly unity. The observational situation are similar for the other events introduced in the references above.

We performed Mote Carlo calculation assuming neutron spectrum proportional to $\mathrm{T_n}^{-\alpha}$, where $\mathrm{T_n}$ is kinetic energy of neutrons. Time dispersion and decay during the flight between the sun and the earth, attenuation in the earth's atmosphere, detector response are all calculated. The resultant hardness ratio for a conventional power law index, 4.5, was ∼0.03 when counting rate reaches at the peak at 300 sec after light. This considerable difference from the observation (∼1) has puzzled us.

As first suspected, we further studied the relation between the hardness ratio and the power law index of the primary neutrons. For α=2.5, we found hardness ratio evolves from 0.08 to 0.03 in time. Maximum value, 0.08, is determined because the highest energy of the Monte Carlo calculation for the atmospheric attenuation is limited at 1700 MeV [4]. Because high energy neutrons arrives in a short time interval, even with a power law spectrum highest energy particles significantly contribute to the time profile when the spectrum is hard. This was not the case for α=4.5 where the maximum count appears at 300 sec meaning that the contribution from 250 MeV neutrons is significant.

To extend the maximum energy for the calculation of atmospheric attenuation, we decided to use GEANT4.6.2 with the QGSP Bert model [7]. The MC package must be able to treat pion generation and must agree with the basic results of [4] below 1 GeV. GEANT4 satisfied these requirements. When we simulated neutrons with α=2.5 and energies between 10 GeV and 50 GeV, the hardness ratio became 0.2. The result agrees well with the observational value in the statistical error.

4. Discussion

Though $>$10 GeV neutrons arrive within 2 seconds, the excess seen in the observations continued for about 2 minutes. We can not deduce the evolution of hardness ratio during 2 minutes because of the limited statistics. As explained above, with α=2.5 highest energy neutrons mostly determine the detector's response. If the emission lasts 2 minutes with α=2.5, it can explain average hardness ratio of $\sim$0.2 during 2 minutes.

To explain the observed excess count of S1_Anti, we need a solar neutron emission flux on the sun to be, $2 \times 10^{26} \times (\mathrm{T_n}/100\mathrm{MeV})^{-2.5}$ $\mathrm{MeV^{-1}}$ $\mathrm{sr^{-1}}$. Independent calculations to explain the Mauna Kea SNT count rate concludes that we also need $2 \times 10^{26} \times (\mathrm{T_n}/100\mathrm{MeV})^{-2.5}$ $\mathrm{MeV^{-1}}$ $\mathrm{sr^{-1}}$ emission. We must note that the Mauna Kea SNT suffers ambiguous heavy attenuation from the Subaru telescope structure when the sun is in the north-west direction as was the case in this event. In the calculation above, we included 1 m thick concrete around the detector.

With such high energy primary neutrons, GEANT4 predicts not only neutrons but also comparable number of muons and gamma-rays to arrive at the detector. Because the SNT has sensitivity to these particles, there appears a difference from the neutron monitor response, which is mainly sensitive to hadrons. Assuming the neutron flux deduced above and considering the NM efficiency to the hadrons, the expected excess count of NM at Norikura is calculated to be $\sim$400, that is 1.5σ excess in 2 minutes. This explains why the NM data shows only very marginal bump at that time. Because the efficiency of NM for muons is estimated to be 1% of that for hadrons [8], contribution from muons is negligible in the present case.

5. Conclusions

We studied a solar neutron event associated with the 28 May 2003 solar flare. An emission of very high energy ($>$10 GeV) neutrons with a power index of 2.5 is necessary to explain the high hardness ratio observed in the Norikura SNT. Because high energy neutrons from such a hard spectrum concentrate in very short time intervals, 2 seconds, they can dominate the detector response. Consequently, observed time dispersion of 2 minutes is attributed to its emission on the sun. From the observations at two different places, Norikura and Mauna Kea, we obtained the same flux of neutrons independently. The estimated flux is one order of magnitude weaker at 100 MeV than so far reported solar neutron events. However total energy emitted between 100 MeV and 100 GeV is almost same. Because the $>$10 GeV neutrons generates considerable number of non hadronic component in the atmosphere, SNTs are suitable to observe such events than neutron monitors.

As repeated, neutrons with hard spectrum results a very short excess in the detector. If the emission is instantaneous, solar neutron event lasting only 1 second is possible at an observable level with a moderate flux. We must pay attention for such missing phenomenon.

References

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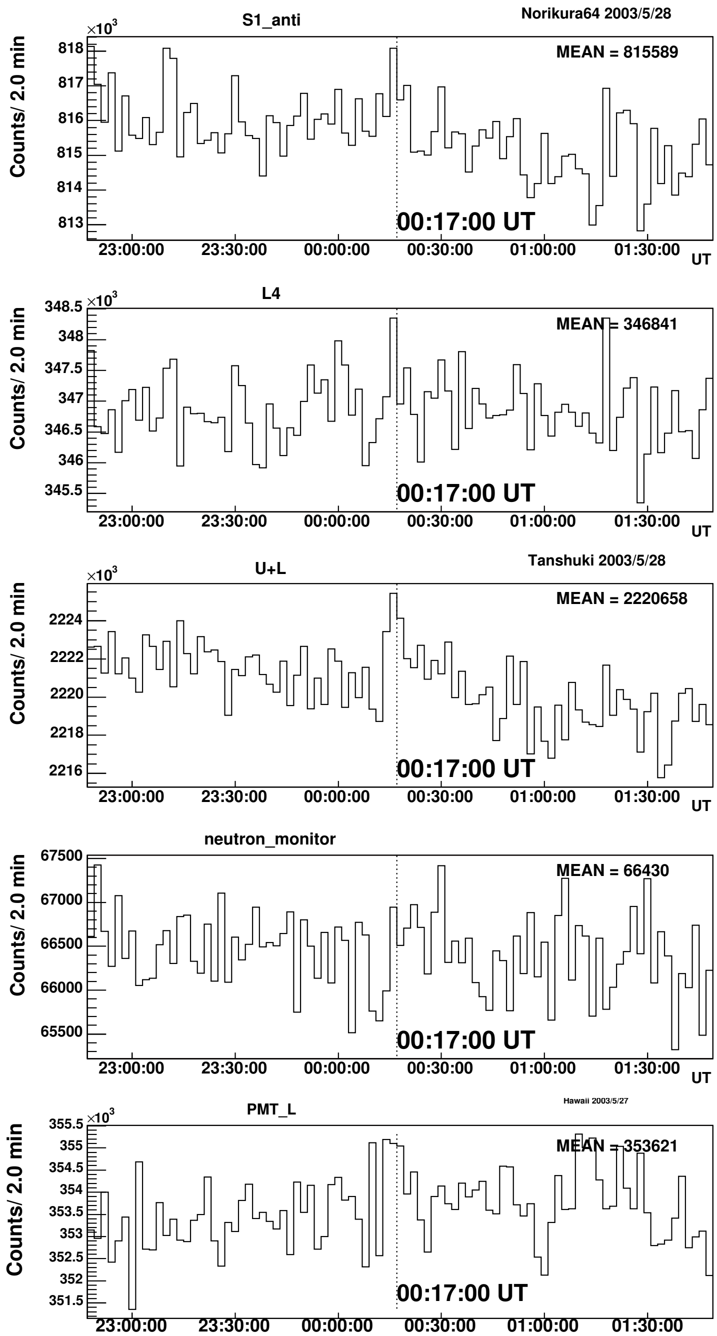

Figure 1. Counting rate profile around the solar flare occurred at 0:17 UT on 28 May 2003. Top panel shows count of scintillator of Norikura SNT (S1_Anti). Second shows count for penetrating particles of Norikura SNT (L4). Third panel shows scintillator count of the Norikura muon telescope. Fourth shows Neutron Monitor at Mt.Norikura. Bottom panel shows counting rate of scintillator of Mauna Kea SNT.