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Observation of Solar Neutrons by the World-Wide Network of Solar Neutron Detectors

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Abstract

A new network to observe solar neutrons for 24 hours has been operating since 1998. There are five stations in this network; Mt.Norikura, Mt.Chacaltaya, Mauna Kea, Mt.Aragats, and Mt.Gornergrat. Each detector has a capability of measuring the energy of neutrons. Coincidentally, the Sun has entered an active phase since the end of 1997, and 17 solar flares of X-class have already been recorded by the end of April 1999 during the solar cycle 23. The results of observations obtained by the world-wide network of solar neutron detectors in association with X-class solar flares at solar cycle 23 are presented.

1 Introduction:

Observation of solar neutrons can provide us with unique information on the acceleration of ions to high energies in solar flares. It is required, however, that a solar neutron detector has an capability of measuring the energy of neutrons. Neutron have a mass and we cannot know the timing nor the duration of the solar flare without knowledge of the energy of neutrons. A new global network to observe solar neutrons 24 hours has been made. Each detector has the capability to measure the energy of neutrons by the total track length of recoil protons. The first detector was constructed at Mt. Norikura (2,770m). Although the effective area was only 1 m^2, it successfully detected high energy neutrons from the large flare on June 4, 1991 (Muraki et al., 1992).

The construction of the new network commenced in 1992. The Bolivian detector has an area of 4m^2 and has been operating at Mt. Chacaltaya (5,250m) since September, 1992. In Norikura, the construction of a huge 64m^2 telescope was completed in 1996. Two stations were added in 1997, one has an area of 4m^2 and was constructed at Mt. Aragats (3,250m) in Armenia, and another one which has an area of 8m^2 was constructed at Mauna Kea (4,200m) in Hawaii. Furthermore, a 4m^2 telescope was operated in the beginning of 1998 at Gornergrat (3,135m) in Switzerland and the whole network was completed.

Detection efficiencies for these detectors were calibrated using neutron beams at the Research Center for Nuclear Physics, Osaka University, in the neutron energy range between 100 MeV and 300 MeV (Tsuchiya et al. 1999).

2 Experiment:

There are 6 detectors in the new network, and each detector is placed at a high altitude in a different longitude. Each detector in the network consists of either scintillation counters or proportional counters, or both. Although the counters and the area of each detector are not the same, every detector can discriminate charged particles from neutrons, and has an ability to measure the energy of incident neutrons. In order to measure the energy of a neutron, the total track length of a recoil proton produced by n-p reactions is measured. Some of the detctors are able to measure the direction of neutrons, and it is possible to determine if the excess is from the Sun. Neutron signals are counted every 10 seconds in each detector.

Table 1: Characteristics of solar neutron detectors in the world-wide

Place (country)	Altitude	Area	Type of Counters	Energy Range (MeV)	Direction
Norikura (Japan)	2,770m	64m^2	SCINTI & PRC	>40, >80, >120, >160 >350, >450, >550	Yes
		1m^2	SCINTI	50–360, 280–500, >390	Yes
Chacaltaya (Bolivia)	5,250m	4m^2	SCINTI	>40, >80, >120, >160	No
Aragats (Armenia)	3,250m	4m^2	SCINTI	>40, >80, >120, >160	No
Mauna Kea (USA)	4,200m	8m^2	PRC	>80, >230, >300	Yes
Gornergrat (Switzerland)	3,135m	4m^2	SCINTI & PRC	>40, >80, >120, >160	preparing

Characteristics of 6 detectors are briefly summarized in Table 1. In the column of 'Type of Counters,' SCINTI is an abbreviation of scintillation counters, and PRC is that of proportional counters. Two detectors, the new $64m^2$ telescope and the original $1m^2$ telescope, are operated at Norikura. Another telescope, which has an area of $9m^2$, has been in operation since September, 1998 in Tibet (4,300m). Details of the Tibet detector and its observational results are presented in Muraki et al. (1999) and Katayose et al. (1999).

3 Analysis:

The Sun has been active since the end of November, 1997. The number of X-class flares from November, 1997 to April, 1999 is 17. These flares were observed at four clustering periods, three in November, 1997, four in April-May, 1998, five in August, 1998, and five in November, 1998. The excess of counts of neutron channels compared to one hour averages was investigated during these 17 flares. Class X is defined by the X-ray flux at 0.1–0.8nm observed by the GOES satellite. The time which gives the maximum X-ray flux sometimes differs from that observed by BATSE hard X-ray channels, which covers between 30MeV and 60MeV. On the other hand, the interval of sampling counts by our detectors is 10 seconds, and it is possible to calculate the excess count every 1 minute, 3 minutes, and so on. There is also information on several energy ranges at each time interval. Therefore, excesses by solar neutrons were searched for various time intervals and energy channels at least $\pm$1hour from the peak time of GOES X-ray data.

4 Results and Discussions:

We found no excess of neutron signals exceeding 4 σ in association with 17 X-class flares. However, excesses higher than 3 σ were obtained associated with three X-class flares. One was observed at Chacaltaya on November 6, 1997, and the other two were observed at Mauna Kea on August 17 and August 18, 1998. The event on November 6, 1997 is presented in Matsubara et al. (1999). A summary of two solar flares on August 17, and 18, 1998 is listed in Table 2. In the table, LT is an abbreviation of "local time."

Table 2: Solar flares on August 17 and August 18, 1998

Date	GOES	Neutron (Mauna Kea)	Yohkoh (hard X-ray)	BATSE
August 17	X=1.2 position: unknown start 21:10UT max 21:20UT	3σ 21:15-21:16UT (11:15-11:16LT)	no data	start 21:22UT max 21:22.5UT
August 18	X=4.9 position: N33E87 start 22:10UT max 22:19UT	3.3σ 22:13-22:14UT (12:13-12:14LT)	start 22:14UT max 22:16UT	no data

On August 18, gamma rays were also detected upto $\sim$ 20MeV by the Yohkoh Gamma Ray Spectrometer. In the gamma ray spectrum, neither the 2.2 MeV line of neutron capture nor other excited lines were detected (Yoshimori, Shiozawa, and Suga, 1999). And the peak time of the gamma ray flux was 22:16UT, a few minutes after the excess at the Mauna Kea neutron detector. Therefore, it is possible that protons were accelerated very efficiently to higher than 1 GeV energies just after the onset of the flare, if the excess obtained by our detector at Mauna Kea was due to solar neutrons. Figure 1 represents the excess obtained at Mauna Kea on August 18, 1998.

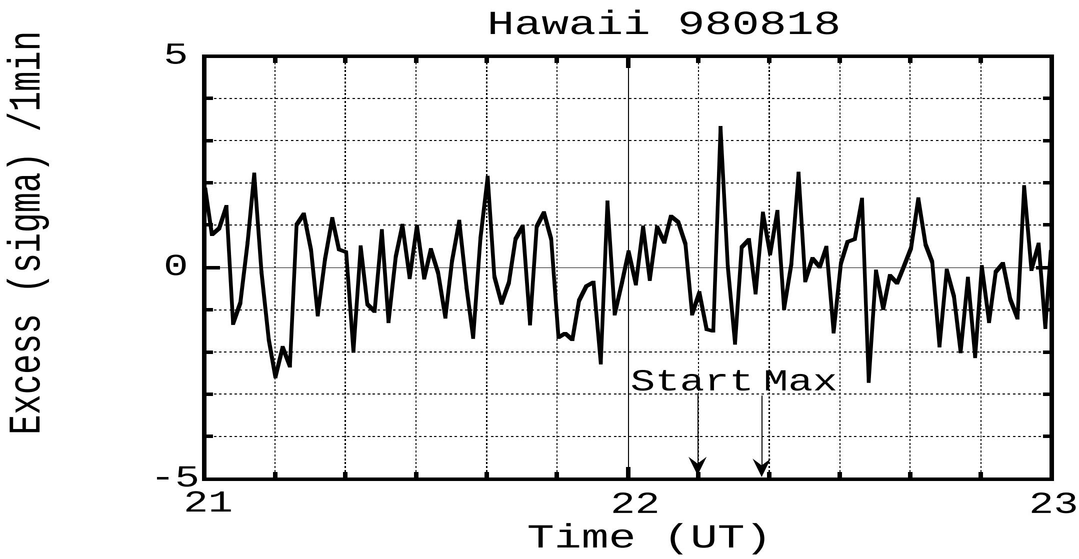

Figure 1: Excesses of counts per one minute at the Mauna Kea detector on August 18, 1998. The start time is measured by the GOES satellite and is 22:10UT.

5 Summary:

The world-wide network of the solar neutron detectors are ready for the maximum of the solar cycle 23. Every detector in the network can discriminate charged particles from neutrons, and has a capability to measure the energy of incident neutrons. Although no events confirming the existence of solar neutrons has been detected so far, there were several events which were suggestive of detections of neutrons from the Sun. It is expected that this network will play a very important role in the study of the acceleration mechanism of ions during solar cycle 23.

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