Possible Observation of Solar Neutrons on November 6, 1997 at Chacaltaya

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Abstract

In November, 1997, three X-class flares were observed at the solar surface. Hard X-rays and gamma rays were detected by "Yohkoh" in the case of the X-class flare on November 6. The X-ray flux reached its maximum at 7:56 am in Bolivian local time in this flare. The solar neutron detector at Mt. Chacaltaya is 5250m above sea level. Neutrons (>500 MeV) must be attenuated by a factor of 10^{-3} in the atmosphere at 7:56 am in November 6, which is not the best time for neutron observation. However, the number of neutrons during 3 minutes increased by a significance level of 3σ in 4 different energy ranges of neutrons (>40MeV, >80MeV, >120MeV, >160MeV). This may be an indication of the detection of solar neutrons, although the statistics are not significant enough. Details of the flare and the observational result at Mt.Chacaltaya are presented.

1 Introduction:

A new type of solar neutron detector has been in operation since September 1992 at Mt. Chacaltaya, 5250 m above sea level and near the equator (16°21′S and 68°08′ W) (Matsubara et al., 1993). The height and the location of Chacaltaya provide excellent conditions for detecting solar neutrons. The energy of incident neutrons is measured by the total track length of protons produced inside plastic scintillators by n-p reactions. An ability to measure the energy of neutrons is essential in identifying the production time of neutrons. In March 1994, an anticounter system to veto charged particles was added.

The Sun has become active since the end of 1997, and three X-class flares were detected in November, 1997. The solar flare which occurred on November 6, 1997, was the largest among all those that occurred during solar cycle 23. The maximum flux of X-rays was observed at 11:55UT, which corresponds to 7:55am in Bolivia. Neutrons with an energy of >100MeV are expected to be attenuated by a factor of 10^{-4} when they are observed by the detector at Chacaltaya, if neutrons propagate in the atmosphere undeflected. However, if a systematic scattering effect into the direction of the atmospheric density gradient is taken into account, neutrons and protons will traverse a significantly smaller mass path than the line-of-sight path (Smart, Shea, and O'Brien, 1995). This was case for the solar neutron event on May 24, 1990 (Debrunner, Lockwood, and Lyan, 1993, Debrunner et al. 1997). Therefore it is worthwhile to search for neutron signals in the detector of Chacaltaya on November 6, 1997. According to our calculation (Tsuchiya et al. 1999a), the attenuation is expected to be 10^{-3} for neutrons with an energy of >500 MeV at Chacaltaya as shown in Figure 1.

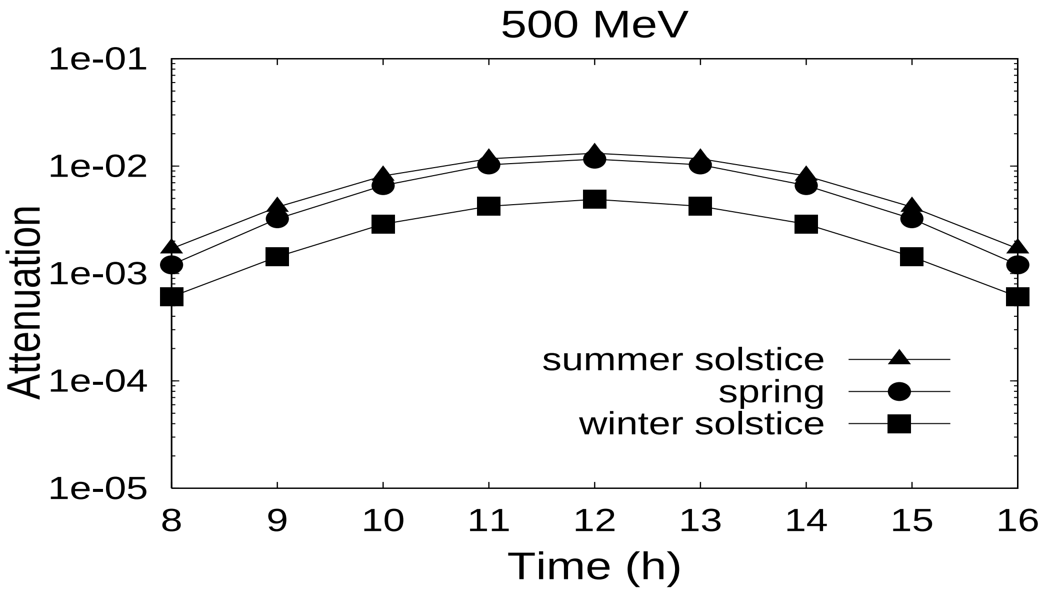

Figure 1: Attenuation of neutrons (>500 MeV) at Chacaltaya.

2 Experiment

The main detector in this experiment consists of four 1m^2 plastic scintillators with a thickness of 40cm. Neutrons are detected when protons are produced inside plastic scintillators by (n,p) reactions. The pulse height obtained by each photomultiplier is discriminated with four threshold levels corresponding to the energy of a recoil proton of 40MeV, 80MeV, 120MeV, and 160MeV. Single counts of these four channels in each scintillator are recorded every 10 seconds. Typical counts $(10\text{sec}\cdot 4\text{m}^2)^{-1}$ are 40,000 (>40MeV), 22,000 (>80MeV), 12,000 (>120MeV), and 5,100 (>160MeV) respectively.

The anticounter system to veto charged particles consists of 17 scintillators, each of which has an area of 220cm×46cm and a thickness of 1cm. The top of the main detector is covered by 5 antiscintillators and each side by 3 antiscintillators. The backgrounds due to charged particles are reduced to one half of the above values at lower energies and one third at higher energies. A schematic view of the detector is shown in Figure 2.

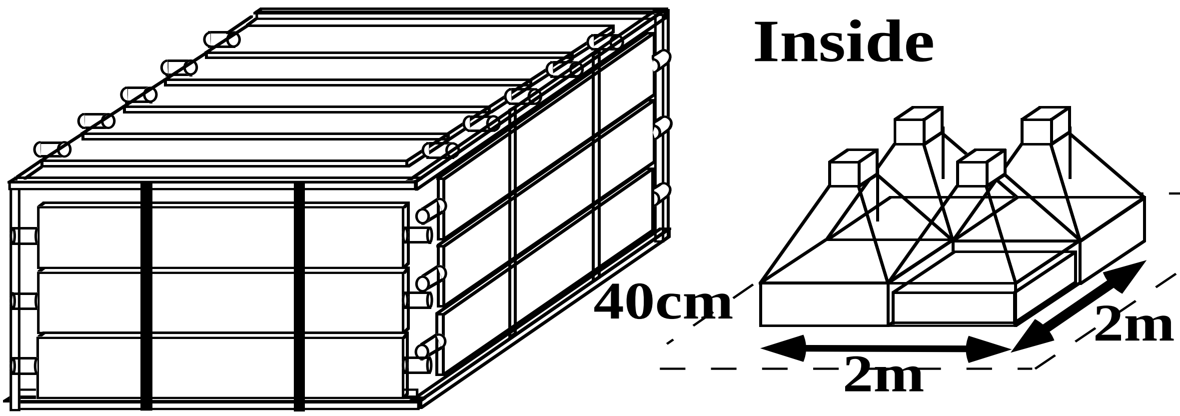

Figure 2: A schematic view of the solar neutron detector at Chacaltaya.

3 Solar Flares on November 6, 1997:

The GOES satellite recorded a large solar flare (X9.4) on November 6, 1997, successively after the X2.1 class flare on November 4. This flare occurred at 11:49UT and the X-ray flux achieved its peak at 11:55UT. The position of the flare was on the solar surface S16W43. Enhancement of the proton flux was also seen by the GOES satellite after 12:00UT. Ground level enhancements were also seen by several neutron monitors.

This flare showed the largest photon counts in four energy bands of X-rays (14-23 keV, 23-33 keV, 33-53 keV, and 53-94 keV) among all the flares ever detected by the Yohkoh satellite (Sato et al. 1999). The flux of hard X-rays peaked between 11:53UT and 11:54UT, slightly earlier than the peak of soft X-rays measured by GOES, the energy of which corresponds to 1.6-12keV. Gamma rays were also detected up to $\sim$ 20MeV by the Yohkoh Gamma Ray Spectrometer. In the gamma ray spectrum, the neutron capture line of 2.2 MeV and the 4.4 MeV excited line of carbon were detected (Yoshimori et al. 1999).

4 Chacaltaya Results and Discussions:

In the analysis, the signal counts corresponding to neutrons, which were vetoed by charged particles, were summed every three minutes. The statistical excess of every three minute counting rate was compared with the one hour average taken $\pm$30 minutes from the particular time. The excess of each counting rate was calculated by subtracting the one hour average and dividing it by the statistical fluctuation from the average. Excesses thus obtained are shown in Figure 3 as a function of local time. Four figures correspond to four different energy thresholds, ch1: $>$40MeV, ch2: $>$80MeV, ch3: $>$120MeV, and ch4: $>$160MeV. Dotted lines are the onset of the flare (11:49UT).

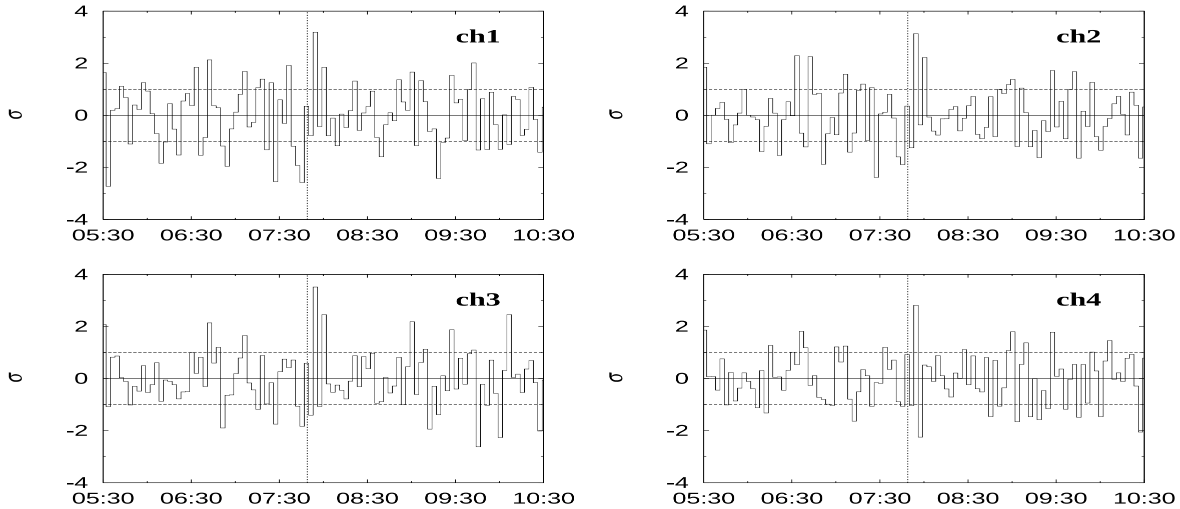

Figure 3: Excesses of counts per three minutes are shown. Details are described in the text.

It is shown that $\geq 3\ \sigma$ excesses were obtained for four different energy thresholds at Bolivian local time 7:51-7:54am (11:51-11:54UT). This time interval contains the onset of gamma ray lines (11:53.5UT). These excesses are not statistical confirmation of a solar neutrons detection. However, neutrons $\geq$1 GeV should have been detected, if these excesses were real and neutrons were produced at the same time as the onset of gamma ray lines.

In the case of the X9.3 event on May 24, 1990, the apparent attenuation length of neutrons was 208 g/cm^2 (Smart, Shea, and O'Brien, 1995) because of the atmospheric density gradient effect as was discussed in section 1. The detection efficiency of the Bolivian detector to neutrons is $\sim$ 20% for neutrons, energies of which are above 300 MeV (Tsuchiya et al. 1999b). By adopting these values, the integrated flux of neutrons ($\geq$1 GeV) at the top of the atmoshere, is calculated to be 2.2×10^6 m^{-2}. This value is the same as that calculated for the event on May 24, 1990 (see Fig. 1 in Shibata, Murakami, and Muraki, 1993).

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