Solar Neutron Event in Association with the 24 September 2001 Flare

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Abstract

Solar neutrons have been detected using the Tibet Solar Neutron Telescope to be associated with an X2.6 class solar flare that occurred at 9:32 UT, 24 September 2001. Neutrons with kinetic energies more than 300 MeV were detected with a statistical significance of 4.6σ just 2 minutes after the flare onset time. The arrival direction of the neutrons were well collimated with the direction of the sun after taking atmospheric scattering into account.

1. Introduction

Solar neutrons are among the best probes for investigating ion acceleration during a solar flare. Solar Neutron Telescopes are designed to observe specifically solar neutrons [1]. They have anti-coincidence counters, a direction measurement capability, and also a calorimeter to derive information on the energy spectrum. In this paper, we present observations of a solar neutron event, using the Tibet Solar Neutron Telescope, associated with a solar flare that occurred on 24 September 2001. First, the flare is briefly introduced and the detector and results of observation are described. The results are compared with Monte Carlo calculations.

2. Flare

The flare began at 9:32UT on 24 September, 2001 in NOAA region 9632 (S16° E23°) and reached the X-ray class of X2.6. No significant increase of hard X-rays and gamma-rays was found by the Yohkoh satellite around the start time. A proton event was observed a few hours after the start time.

pp. 3175–3178

At the flare start time, Solar Neutron Telescopes in Armenia, Switzerland and Tibet (China) were in the day time zone. Although the zenith angle to the sun was smallest in Armenia, the different properties of the telescopes, *i.e.*, altitude, effective area, direction measurement capability, made the Tibet telescope the most suitable for the observation of this flare. The position of the sun was 30° in elevation and 69° west from south at the site, which is at Yangbajing, Tibet, China (4300m a.s.l., 30.1°N, 90.5°E, 603g/cm^2 vertical air mass).

3. Tibet Solar Neutron Telescope and Observation

The Tibet Solar Neutron Telescope is composed of 3m×3m×40cm plastic scintillator and 4 layers of orthogonally-aligned Proportional Counters (PRCs). Each layer contains 30 PRCs. Incoming neutrons are converted into charged particles in the scintillator. The direction of a recoiled particle is measured using PRCs. 9 directions both in EW (±50° from the zenith) and NS (±41°), *i.e.*, a total of 81 directions, are monitored. The counting rate of each channel is recorded every 10 seconds. Because a total of 20cm thickness of wood absorber is inserted, the estimated energy threshold for vertically incident events is 230MeV. Charged particles are rejected using veto PRCs surrounding the scintillators. Further details of the detector have been described by Katayose et al.[2]

Because high energy neutrons arrive at the earth within a few minutes if their emission is instantaneous, the data is binned every 2 minutes. Standard deviations from the running average are defined to 1σ and a significance map of the 81 directions at 9:34UT is derived, as shown in the top-left of Fig.1., where an excess concentration towards the west is seen. Such an excess is not found for other times and directions. 14 channels (enclosed by dark lines in the Figure) were selected and the combined counting rate for the day is shown at the bottom with the running average and 1σ deviation. A distribution of the significance of the day is shown in the top-right, confirming that the estimation of the significance is correct. The most significant excess (4.58σ) is marked as '9:34UT', which is also the time of the significance map.

4. Simulation

The response of the detector was simulated for a possible solar neutron spectrum. In the simulation, we assume neutrons are released with a power law spectrum (index –4.5) in kinetic energy at the sun, in-flight decay was included. The attenuation in the earth's atmosphere was calculated using Shibata's model [3] and the response of the detector was obtained using Geant 3.21. In the left panel of Fig.2., the angular distribution of neutrons at the top of the detector is shown with the field of view of the Tibet Solar Neutron Telescope.

The filled star indicates the position of the sun at the flare start time. The

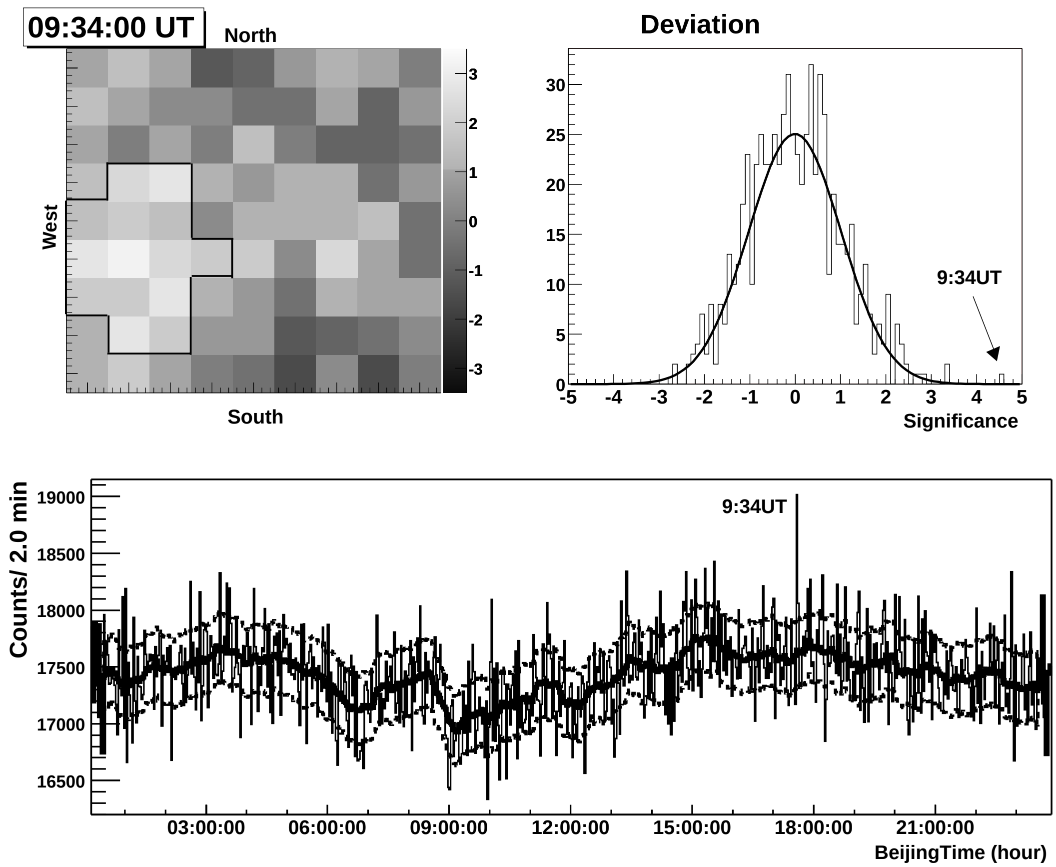

Fig. 1. The event observed on 24 September 2001. Top-left: A significance map of the 81 directions. Top-right: A significance distribution of the day for the combined counting rate of the 14 selected directions. Bottom: 2 min counting rate of the combined 14 directions.

open star shows the expected arrival direction of solar neutrons after being scattered in the atmosphere [4]: it is well overlapped on the results of the Monte Carlo calculation (contours). The position and spread are also very similar to the observational result. The right panel shows an expected significance map (graduation linearly and arbitrary scaled) of the event. After including the detector response, the arrival direction moves to the zenith and some difference with respect to the observations is found. Because we compare the map in terms of significance, it is affected by the background counting rate. In the simulation, the background rate has also been simulated. In the next step, we must verify the consistency of the background estimation.

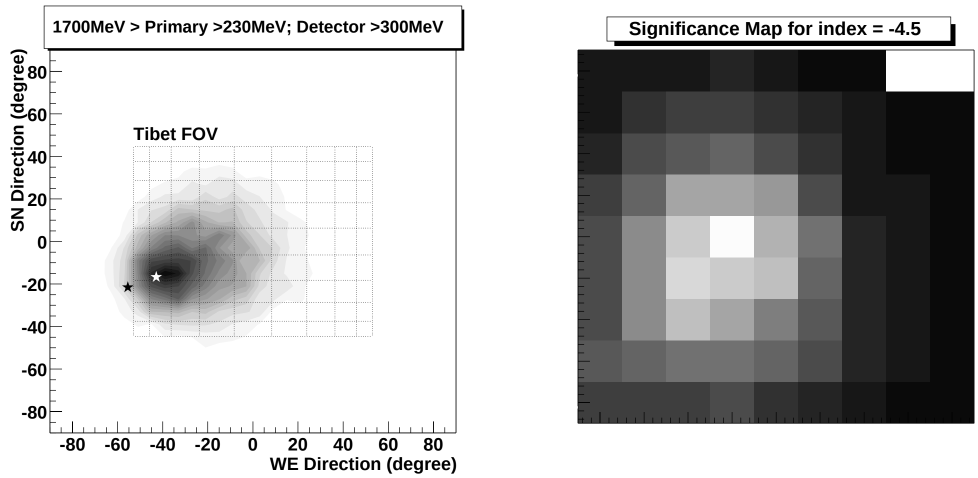

Fig. 2. Simulated arrival direction of neutrons. Left: At the top of the detector. Right: After including the detector response.

5. Summary

Solar neutrons have been observed in association with the flare on 24 September 2001 at a significance level of 4.6σ, using the Tibet Solar Neutron Telescope. The arrival direction is well collimated with the expected solar position after taking atmospheric scattering into account. Some difference is found when considering the response of the detector. It will be necessary to investigate the detector response to background particles.

If the neutrons were emitted at the flare start time (9:32UT), the observed excess found in 9:34-9:36UT is caused by neutrons with kinetic energies 335–650MeV. This is a quite reasonable value compared with past observations and the detector threshold.

Although Watanabe et al.[5] indicated that solar neutrons seem to be accompanied by hard X-rays and gamma-rays, no such emissions were observed around 9:32UT in this event. This suggests an existence of a variety of acceleration/emission mechanism among the solar flares.

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