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The Solar Event on 20 January 2005 observed with the Tibet YBJ Neutron monitor observatory.

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The X7.1 class flare of 20 January 2005 has produced a ground level enhancement (GLE) event which was observed with several neutron monitor observatories. The Tibet Yangbajing Neutron monitor (here after YBJ NM) located at the existing highest cutoff observatory has also observed a GLE starting at 6:49 UT, involving a 2% of peak excess from background. This indicates an extremity hard spectrum of solar nucleons accelerated near the Sun associated with this solar flare. We modeled this GLE by a spherical distribution with a first order anisotropy and also derived rigidity spectrum as a modified power law. A strong anisotropy was found in early phase of this GLE. We also calculated the YBJ NM response function to solar neutrons and search the data for relativistic solar neutrons.

1. Introduction

The X7.1 class flare on January 20, 2005 produced the hardest and most energetic proton event of Solar Cycle 23. The >100 MeV protons observed by GOES was the highest flux level since October 1989. This proton event rose to their maximum intensity level within ~30 minute from onset of x-ray flare at 06:36 UT. SOHO/LASCO observed halo CME at 6:54 UT (appearance time) accompany with this flare. Such unusual rapid and hard increases of the proton intensity challenge the current space weather strategy.

Several neutron monitors have also observed this large relativistic solar nucleon event and recorded it as the largest GLE since 1989. Figure 1 shows count rate increases (in percent) measured by 12 neutron monitor stations between 06:00 UT and 10:00 UT on January 20, 2005. The GLE onsets were around 06:48 UT and high latitude observatories measured up to 400 % of increase. As the figure shows, some stations recorded two peaks in intensity while others observed a single peak with different maximum times. These features have also been observed in previous large GLE events (cf. December 7, 1982 [5], September 22, 1989). Some mid-low latitude observatories shown in figure 1b also observed a small increase, which indicates that protons were accelerated to energies of several GeV.

The Tibet YBJ NM [9], located at the highest cutoff rigidity (14.1 GV; 30.11N 90.53E, 4300m above sea level) among reliable neutron monitors, also observed this GLE. Figure 2 shows the YBJ NM 1 minute averaged count rate increases (in percent) between 06:00UT and 10:00UT. Top and bottom panels show increases of regular neutron monitor count rates and multiplicity 1 channel's count rates, respectively. The onset of GLE was 06:49 UT and the peak intensity was ~ 2% at 07:05 UT.

In this paper we report a modeling of this GLE event, and search the YBJ NM data for relativistic solar neutrons.

2. Modeling of GLE

We modeled the GLE event in two steps, first evaluate spherical distribution using low cutoff data and then derive rigidity spectrum from high cutoff data. As a first step, to model spherical distribution, we fit the data from the 8 neutron monitors shown in figure 1a to a simple first-order function:

$$f(\theta,\phi) = \eta(1 + \xi_x \sin\theta\cos\phi + \xi_y \sin\theta\sin\phi + \xi_z \cos\theta),$$

where $f(\theta,\varphi)$ is the intensity measured by a station with an asymptotic viewing direction defined by θ (colatitude) and φ (longitude), η is the particle density, and (ξ_x, ξ_y, ξ_z) are the three components of the anisotropy vector [1][2].

Results of the first-order fit are shown in figure 3. Top panel shows the cosmic ray density expressed as increase above the Galactic cosmic rays background. Bottom panel shows anisotropy defined as $\xi = (\xi_x^2 + \xi_y^2 + \xi_z^2)^{1/2}$. A strong anisotropy is seen in early phase of this GLE. This indicates relativistic solar nucleons accelerated directory by flare have passed thorough along the field line.

Next, we determine the solar proton spectrum. We followed the procedure of Cramp et al. [5][6], and searched for the parameters that can best reproduce the observed increases when convolved with the responses of individual stations. Assuming the spatial distribution of the proton source location dose not depends on the energy, then response of the neutron monitors to solar protons can be express as:

$$\frac{\Delta N}{N} = \frac{1}{9}\sum_{(\theta,\phi)=1}^{9} \frac{\sum_{P\min}^{P\max} Q_{(\theta,\phi)}(P)J(P)S(P)G(\alpha)\Delta P}{\sum_{P\min}^{\infty} Q_{(\theta,\phi)}(P)J_0(P)S(P)\Delta P},$$

where, ΔN and N are the count rate increase due to solar proton and the baseline count rate of the Galactic cosmic rays, respectively, P is the particle rigidity (GV), Q=1 indicates accessible directions of protons arriving from θ (zenith) and φ (azimuth) coordinates, J is the differential solar proton flux, J_0 is the interplanetary differential nucleon flux adjusted with solar cycle modulation, S is the neutron monitor yield function due to Clem and Dorman [4], and G(α) is pitch angle

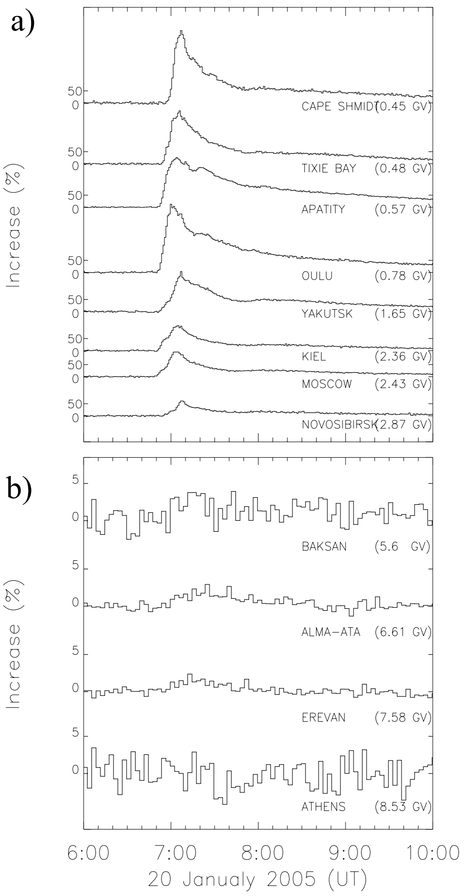


Figure 1. Neutron monitor count rate increases (in percent) between 0600UT and 1000UT on 20 January 2005. From top to bottom, data from 13 stations are displayed in the increasing order of the cutoff rigidity. Each station name and its cutoff rigidity are shown as well.

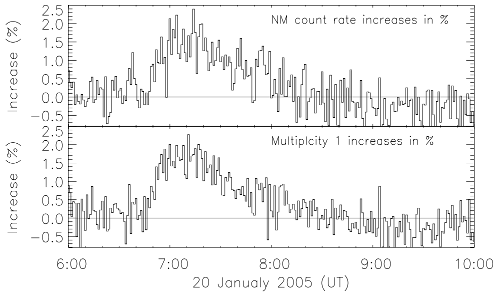
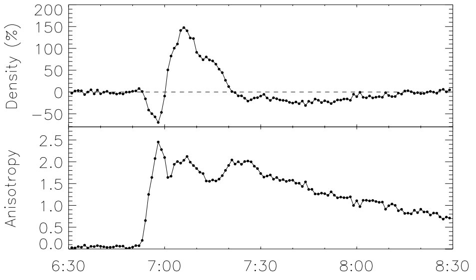
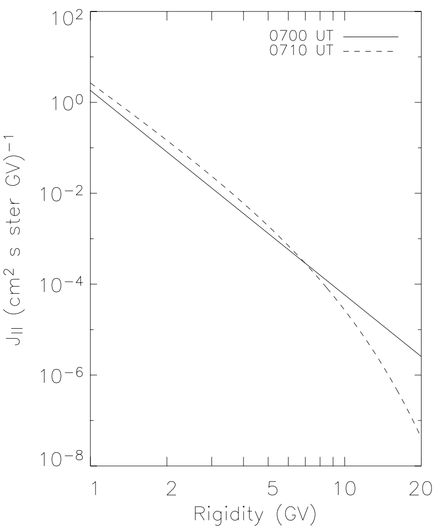


Figure 2. The GLE observed by the YBJ NM. Top and bottom panel shows, count rate increase (in percent) of neutron monitor count rates and multiplicity 1 channel's count rates.





(Left) **Figure 3**. Result of a first order anisotropy fitting. The cosmic ray density η in percent (top) and the anisotropy ξ (bottom) are shown.

(Right) **Figure 4**. The derived solar proton rigidity spectra at Earth at 07:00UT (Solid line) and 07:10UT (Dashed line) on January 20, 2005.

distribution of the arriving solar protons where α is pitch angle between the asymptotic direction and the axis of the symmetric source. Asymptotic directions of the arriving protons were calculated as a function of *θ, φ* and the rigidity, by tracing the trajectories of negative particles. The rigidity spectrum of the solar protons has been modeled as a modified power law with three parameters, which are the normalization, the power law exponent γ, and the change of γ per gigavolt as δγ. Thus the slope of the spectrum may increase with rigidity in a way similar to theoretical shock acceleration spectra [7]. We used Tibet, Novosibirsk, Yakutsk and Apatity neutron monitors to derive the best fit model spectrum. Figure 4 shows the derived solar proton rigidity spectra of the present GLE at Earth at 07:00 UT and 07:10 UT where γ and δγ were (-4.5 and 0.0) and (-4.0 and 0.1), respectively. The uncertainties in γ are estimated to be about ±0.5.

3. Search for solar neutrons

During this solar event, Sun was above the YBJ NM and hence we have a good chance to observe relativistic solar neurons. (Although, zenith angle was 51 degree.) A few minutes before the GLE onset time (06:49 UT), the YBJ NM observed a hint of pre-increase between 06:34 UT and 06:43 UT as shown in figure 6 (See also figure 1). In view of the relation to the regular GLE onset, it might be considered as caused by relativistic solar neutrons. However RHESSI observation did not observe any evidence for ion accelerations during this period, and argues against this hypnosis. Rather than this time period, RHESSI has measure nuclear de-excitation line fluxes between 06:44 UT and 07:00 UT (private communication G.H. Share, 2005). This suggests that solar neutron signals, if any, are buried in the main GLE signal.

The YBJ NM yield function for solar neutrons was calculated with using a Monte Carlo code [4] to simulate high energy and nuclear transport. Figure 5 shows the yield function along with related quantities. We simply adopt the same relativistic solar neutron spectrum as October 28, 2003 event [1] as,

$$Q = 1.293\times10^{30} E_n^{3/8} \exp\left[-(E_n/0.016)^{1/4}\right],$$

where Q is the spectrum in units of (sr MeV)$^{-1}$, and E_n is neutron energy in MeV (See also [3]). The onset time and duration were taken from the RHESSI's nucleon de-excitation lines observation and adopt the onset as 6:36 ST (Solar time) with 15 minute duration. We refer to the nuclear de-excitation lines for timing rather than the 2.223MeV gamma ray neutron-capture line. Although the capture line is a direct by-product of

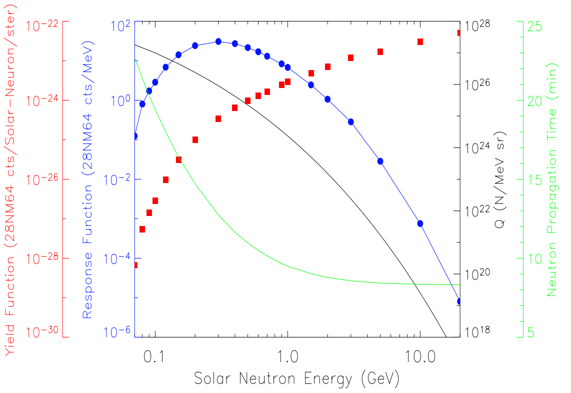


Figure 5. Yangbajing 28-NM-64 yield function versus energy for neutrons arriving 51degree from zenith (red squares). Also shown are the Bieber's [3] exponential spectrum (black curve), the Yangbajing response function (blue), and the propagation time of a neutron from the Sun to 1 AU (green).

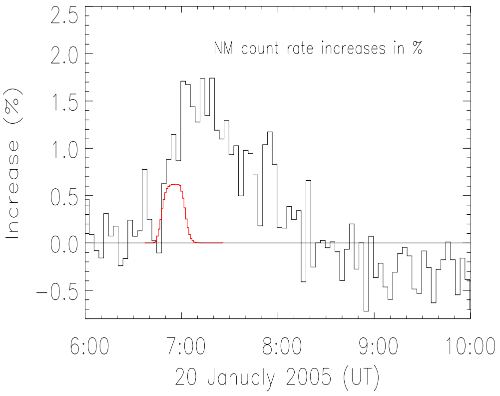


Figure 6. The YBJ NM 3-minute averaged intensity. Red curve is expected intensity increase assuming existence of solar neutron onset at 6:36 ST. See text for detail.

neutron absorptions in the photosphere and serves as an indicator of the integrated flux of neutrons, the timing information is poor due to the long thermalization times (~100s).

As a preliminary analysis, we assume that this event produced the same number of solar neutrons observed during the 23 October, 2003 event. The red curve in figure 6 represents the results from this study. Although the model seems to reproduce the observed onset of NM data fairly well, the YBJ neutron telescope [8], located in the same area, did not observed neutrons during this period [10]. Further investigation is needed to draw a definite conclusion.

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References

[1] J.W. Bieber et al., GRL, 32, L03S02 (2005).
[2] J.W. Bieber et al., ApJ, 601, L103-L106 (2004).
[3] E.L. Chupp, ApJ Suppl., 73, 213 (1990).
[4] J. Clem and L. Dorman, Space Sci. Rev., 93,335 (2000).
[5] J.L. Cramp et al., JGR, 102, A3, 4919 – 4925 (1997)
[6] J.L. Cramp et al., JGR, 102, A11, 24,237 – 24,248 (1997)
[7] E.C. Ellison and R. Ramaty, ApJ, 298, 400-408 (1985).
[8] Y. Katayose et al., 26th ICRC. Salt Lake, (1999) 6, 58.
[9] T. Kohno et al., 26th ICRC. Salt Lake, (1999) 6, 62.
[10] F. Zhu, in this proceedings (2005).