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Variations of solar proton spectrum during the ground level enhancement of 2005 January 20

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The differential power law index of solar proton spectrum deduced from GOES measurements within 80-165 and 165-500 MeV during the ground level enhancement on 20 January 2005 was extremely hard and clearly showed time variations, which indicate two episodes of proton acceleration. The possibility of multi-step acceleration of protons does not contradict to the hard X-ray and γ-ray observations of this flare by instruments aboard RHESSY and INTEGRAL. The power law spectrum extrapolated to higher energies leads to unreasonably large variations of neutron monitor count rate, i.e. the spectrum should be accurately sewed between lower and higher energy parts. Possibly this unknown shape of the spectrum varying in time would determine count rate variations of a particular NM at middle and high latitudes, for instance, the extremely large enhancement observed by the South Pole NM might be explained by this effect.

1.Introduction

Ten years ago inspired by the observations of prolonged γ-emission of solar flares in June 1991 we suggested to search evidences of multi step acceleration in charge particle data [1]. Really the authors of [2] have argued that in long duration soft X-ray events acceleration takes place in shocks in the high corona and leads to a harder proton spectrum than in short duration events where the acceleration take place in lower regions during the impulsive phase. Since hybrids of two classes are possible, then charge particle data at the Earth orbit likely may give an evidence of the multi-step acceleration at the Sun. If a time interval between the acceleration episodes is greater than a time of proton propagation to the Earth, then the spectrum may become harder for some time interval indicating the second acceleration episode. A power law spectrum derived from the observed ratio of 84-200 and 110-500 MeV channel count rates was assumed as a first approximation of solar proton spectrum. The spectral dynamics of solar protons during several hours after a start of microwave emission was studied for powerful solar proton events of the 1989-1992 years in [1]; it was concluded that two-step acceleration is a typical process and a relative contribution of each stage is important.

Using this spectral approximation it is possible to calculate a response of particular NM to such solar protons. In some cases this spectrum leads to unreasonably large variations of NM count rate during ground level enhancements (GLE), i.e. the spectrum should be much softer for NM energies. Therefore, a real shape of the proton spectrum for energies higher than about 500 MeV becomes very important (correct sewing of lower and higher energy parts of the spectrum) appears in the interval of 200-1500 MeV [3]. Because available data from integral detectors do not allows us to derive a precise shape of the proton spectrum, this unknown part of the spectrum, but not the geomagnetic and atmospheric cut off might determine a count rate of a particular high latitude NM.

The unusual spectral dynamics of solar protons observed during the solar energetic particle (SEP) event of January 20, 2005 allows returning back to the above problems and comparing with the previous results of [4,5] for the July 14, 2000 event. The long duration γ-emission observed during the solar flare of 2005 January 20 by INTEGRAL and RHESSI possibly supports the results of [1]. The extremely hard spectrum of solar proton below 500 MeV may cause large enhancement GLE registered by the South Pole NM.

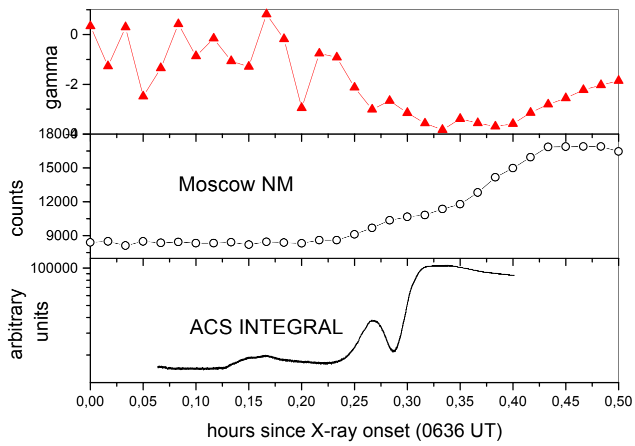

Figure 1. The count rates of ACS INTEGRAL and Moscow NM during the 20 January 2005 event; the differential power law index deduced from proton intensities measured by GOES within 80-165 and 165-500 MeV energy bands

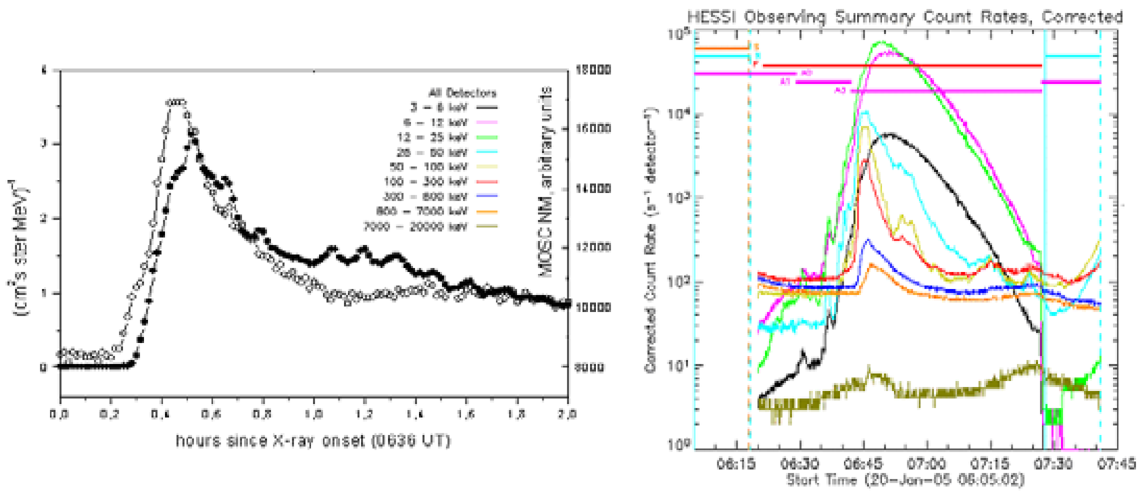

Figure 2. Comparison of the Moscow NM count rate (open circles) and GOES proton intensity within 165-500 MeV (solid circles). RHESSI observing summary count rates.

2. Observations

Several ground and space instruments registered the solar event on 2005 January and associated phenomena in the interplanetary space. Table 1 presents some characteristics of the parent events considered below.

Table 1. Some characteristics of the parent solar events

Date	imp	Onset	Max	End	Opt	Coord.
14 Jul 2000	X5.7	1003	1024	143	3B	N22W07
20 Jan 2005	X7.1	0636	0643	0854	2B	N12W58

Here we compare the count rate of the Anti-Coincidence System (ACS) of Spectrometer on INTEGRAL (bottom panel, Figure1) with count rates measured within different energy channels by RHESSI (Figure 2, right panel). ACS is sensitive to primary γ-rays above ~100 keV as well as to particles and secondary γ-rays from interaction in the telescope and satellite structure. The first gradual enhancement of ACS counts starts at ~0.125 (06:43.5 UT) and corresponds to the soft X-ray maximum (GOES) and the first hump of 7-20 MeV photon count rates (green bottom curve) registered by RHESSI well before the onset of solar protons (Figure 1 and 2). Second two enhancements of ACS counts occurred during the GLE rising phase, when solar protons of 80-500 MeV had the extremely hard spectrum with positive power law index, and might be attributed to both primary and secondary γ-rays. Note the second enhancement of 7-20 MeV photon count rates above the RHESSI background registered from 07:15 to 07:45 UT. It apparently has a harder spectrum.

The time delay between the first γ-ray enhancement and the GLE onset suggests that the same population of protons have produced γ-rays in the solar atmosphere and propagated in the interplanetary space. The spectrum of solar protons becomes harder at ~ 0.875 (07:29) indicating arrival of new population of protons possibly accelerated during the time of the second RHESSI enhancement. Figure 2 compares the GOES proton intensity and the count rate of Moscow. The time profiles were normalized to get a coincidence between their background count rates. We see the difference during the rising phase due to the velocity dispersion and during the decay phase after about one hour since the X-ray onset caused by the new proton population arrived. The time to the first maximum was about ~15 min for 165-500 MeV protons, i.e. the second onset should be at 0.875(07:29 UT). Assuming the proton delay of ~8 min we have the second acceleration (release) of protons at 07:21 UT.

3. Discussion

Let us underline that the observation of two episodes of prolonged solar γ-emission on 2005 January 20 on at a time scale of more than one hour is the first case since the famous events of June 1991 (see [5] an references therein). Just after the second episode of γ-ray emission the proton spectrum became harder indicating the acceleration of protons rather than their storage.

Figure 3 shows the intensity time profiles and spectral dynamics of solar protons during the 2000 July 14 and 20 January 2005 events. We see that the arrival of solar protons was delayed relatively to the X-ray onset by about 15 min in comparison with the 2005 January 20 event. Although behavior of the power law index possibly indicates the proton onset earlier between 10:18 and 10:26 UT on 2000 July 14.The GOES proton intensity has been below background at that time. It looks like first acceleration was depressed on 2000 July 14 in comparison with the second one. Such a possibility was already mentioned in [4]. According to [6] on 2000 July 14 the protons were accelerated at heights between 0.1 –1 of the solar radius above the photosphere, and not in the flaring active region. The first acceleration episode on 2005 January 20 occurred in the flaring region itself, but the second one well above the active region. Possibly using observations of the γ-ray imager aboard RHESSI it would be possible to locate both acceleration sites.

At present we do not know a response function of ACS SPI to primary protons and γ-rays. Comparing the ACS count rate with that of Moscow NM and with spectral dynamics of 80-500 MeV protons, we may conclude that the ACS SPI is extremely sensitive to protons with hard spectrum. The second maximum of the ACS count rate occurred before the onset of 165-500 MeV protons, but after the NM onset. The third largest maximum of the ACS count rate corresponds to the hardest spectrum of solar protons but not their maximum intensity. Separating primary and secondary γ-rays from the ACS counts is a task for the future.

It was shown in [7] that the approximation of the GOES proton spectrum to NM energies during first several hours of the 2000 July 14 event leads to NM variations, which have not been observed in reality. The proton

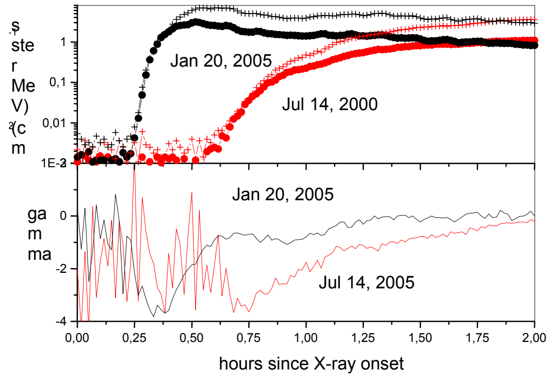

Figure 3. Proton intensities measured by GOES within 80-165 (crosses) and 165-500 MeV (circles) after the X-ray onset of the 14 July 2000 (red) and 20 January 2005 (black) events; gamma - the differential power law index deduced from these intensities.

spectrum on 2005 January 20 was considerably harder (Figure 3). Possibly this unknown shape of the spectrum varying in time would determine count rate variations of a particular NM at middle and high latitudes. For instance, the extremely large enhancement observed by the South Pole NM might be explained by this effect.

4. Summary

1. The observed proton intensities, X-ray and γ-emission time profiles observed on 20 January 2005 provide evidences for two episodes of proton acceleration separated by about 30 minutes.
2. Similar features has the event of 2000 July 14, although the first acceleration episode was depressed.
3. One should take into account the extremely hard spectrum of solar protons below 500 MeV near the Earth on 2005 January 20, which may contribute significantly to NM count rate at high latitudes.

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