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CORONAS-F measurements of high-energy solar proton spectra

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Abstract: Fluxes of protons at the energies 0.8-4 GeV accelerated during solar flares of October-November 2003 were detected onboard the CORONAS-F satellite using the geomagnetic cut-off which were calculated using the geomagnetic field described by IGRF, Tsyganenko models and the Boberg's extension was included for cut-off calculations of the 29 October 2003 event. Measured spectra of 28 and 29 October are in good agreement with ones calculated from neutron monitor network data and measured by GOES satellites.

Introduction

The main method of investigation of solar energetic particle fluxes at energies above ~1 GeV is the analysis of data of the global network of neutron monitors (NM) (e.g. [1-3]). The geomagnetic field acts as a peculiar kind of magnetic spectrometer and different points of location of individual NMs have different values of geomagnetic cut-off rigidity. This method is not direct because NM records secondary particles and the complicate routine is necessary to restore primary fluxes and spectra of solar particles. Other method of energetic solar particle observations is measurement onboard satellites operating inside the Earth's magnetosphere. Each point of a satellite orbit is characterized by a fixed value of cut-off rigidity. If this value differs quickly along satellite motion then one can record solar particles with different energies. In such a manner proton spectra generated by the solar flare of 1 September 1971 were measured onboard MOLNIYA-1 and COSMOS-426 satellites [4-6].

Measurements of high-energy particle fluxes by the CORONAS-F satellite

Similar observations were performed in October-November 2003 onboard the CORONAS-F satellite having the quasi-circular orbit with an altitude ~450 km and an inclination 82º. The SONG (SOlar Neutrons and Gamma rays) instrument consisted of CsI crystal with a diameter of 20 cm and a height of 10 cm [7] and had the geometrical factor equal to 1500 cm^2sr with allowance made for screening by the Earth. One of the SONG channels records events with energy deposition in the crystal > 75 MeV without any additional logical conditions. During the quite time this channel measures fluxes of primary galactic cosmic rays (GCR) and high-energy albedo particles [8]. During solar flares it can also detect solar energetic particles having rigidity above the cut-off value in a current satellite location.

To reduce background count rate level we used data obtained in the same points of satellite orbit two days before the investigated time interval. The analysis of NM and GOES satellites (protons above 700 MeV [9]) demonstrates that high-energy GCR fluxes were practically constant till 11 UT of 28 October (see Fig.1, 28 October is the 301st DOY). Our measurements carried out 26 and 28 October before the onset of solar proton enhancement supports this fact. Figure 2 presents measurements of high-energy particle fluxes in the same space points. Upper and low abscissa axes are combined in such a way that *L*-dependencies coincide. From 11:20 UT we started to observe additional particle fluxes, their intensity depends on cut-off value. This additional flux determined as difference between the "flare" and background count rates is caused by high-energy solar particles.

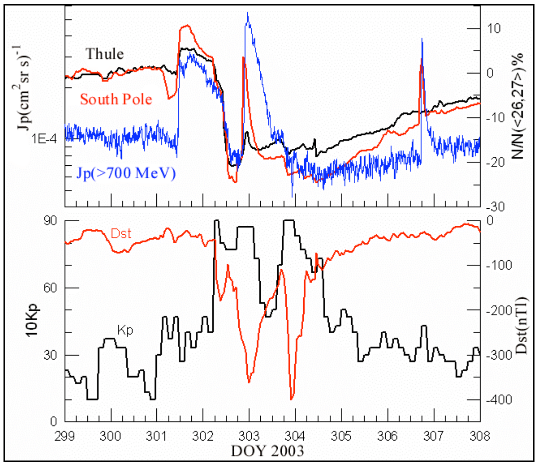

Figure 1: Data of high-latitude NMs and GOES-10 (upper panel) and geomagnetic indices (low panel).

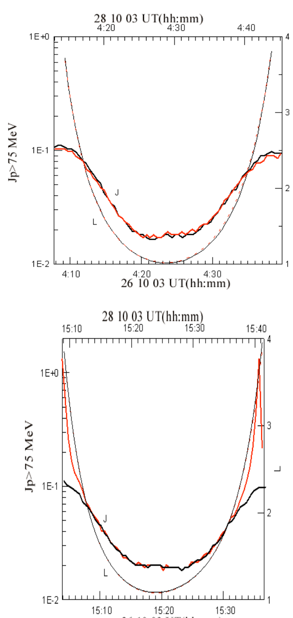

Figure 2: Count rates of high-energy particles measured by SONG on October 26 (black lines) and 28 (red lines) before the solar flare (upper panel) and after solar particle enhancement (low panel). Thin line corresponds to L-parameter

To obtain integral spectra of solar protons we calculated in the standard manner values of geomagnetic cut-off rigidities for set of satellite orbit points. The geomagnetic field was described by a superposition of the IGRF model for the field of inner sources and the Tsyganenko-89 model for the field of outer current systems [10]. The choice of the latter model, in which geomagnetic disturbance is described by a single parameter, *K*p-index, is stipulated by the absence of the data on parameters of the solar wind over the investigated period [11]. We assumed that solar proton spectra may be presented as $J(>E)=I_0E^{-\gamma}$ and calculated values of I_0 and γ. Their magnitudes varied weakly till 06:00 UT on October 29 when the shock wave arrived to the Earth [12].

The hardest solar proton spectrum and the greatest flux were observed at the first three hours of increase. Figure 3 presents these spectra obtained by CORONAS-F as well as calculated from NM data [13]. The last one corresponds to power law spectrum with γ=3.5. These spectra are close to each other within the limits of errors. It should be noted that the strong anisotropy was observed by NM at the beginning of the event. This anisotropy was not observed by CORONAS-F, probably, because of the observation discreteness.

. The flare of 29 October 2003 coincides in time with the strong magnetic storm (Dst=-400 nTl) produced by CME generated by 28 October flare. The Earth's magnetosphere was compressed and usual geomagnetic field models are unsuitable. Beside a deep Forbush-effect had begun at the same time. So the analysis of this event is very difficult however we attempted to study it. Cut-off rigidities were calculated using the Boberg et al. extension [14]. We estimated the magnitude of Forbush-effect as 15-20% using data of global NM network, this value depends weakly on a geomagnetic rigidity. Then we corrected our data using this estimation.

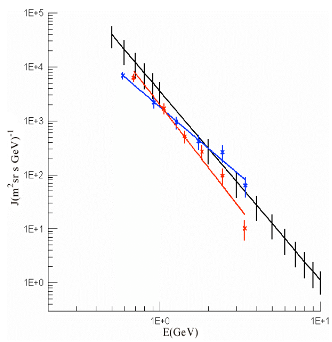

Figure 3: Solar proton spectra on 28 October 2003. Blue line and points – CORONAS-F data at 11:42-11:46 UT (evening sector). Red line and points – CORONAS-F data at 12:04-12:09 UT (morning sector). Black line – NM data at 11:55 UT.

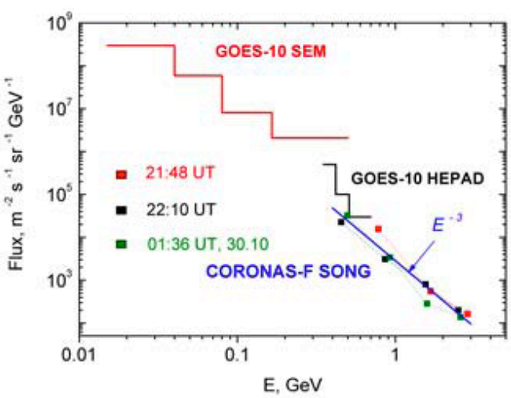

Figure 4: Solar proton spectra on 29 October 2003. Red, black and green squares present the CORONAS-F data.

Figure 4 presents preliminary spectra obtained by CORONAS-F near the flare maximum. The blue line corresponds to the spectrum averaged three measurements. We averaged GOES-10 SEM data [9] and HEPAD ones [15] over 3 hours during the flare maximum.
After flare on November 2high-energy particles were recorded by the CORONAS-F satellite at $L>3$ mainly in the southern hemisphere from the evening Earth's side. We could estimate the proton spectrum only for 21:28 UT on November 2, the index of the integral spectrum γ~3.5.

Conclusions

We illustrated the usefulness of detector having large geometrical factor for energetic particles at low altitude polar orbit for study the evolution of energy spectra of accelerated solar particles using the filtering effect of geomagnetic field. The advantage is also no need of intercalibration.
Combination of energy spectra deduced from NM network with that obtained four times per orbital period of the satellite may serve also for checking the validity of different geomagnetic field models during geomagnetically disturbed periods.

Acknowledgement

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