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Possibilities of the forecast of generation of the high energy solar protons for the safety of Mars mission

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ABSTRACT

During interplanetary flight, after large solar flares, astronauts are subject to the impact of relativistic solar protons. These particles produce an especially strong effect during extravehicular activity or landing on Mars (in the future). The relativistic protons reach the orbits of the Earth and Mars with a delay of several hours relative to solar X-rays and UV radiation. In this paper, we discuss a new opportunity to predict the most dangerous events caused by **Solar Cosmic Rays with protons of maximum (relativistic) energy, known in the of solar-terrestrial physics as *Ground Level Enhancements or Ground Level Events (GLEs)*. This new capability is based on a close relationship between the dangerous events and decrease of *Total Solar Irradiance (TSI)* which precedes these events. This important relationship is revealed for the first time.**

1. Introduction

Ensuring Space flight safety under the effect of hazardous environment is one of the major concerns of all human Space exploration programs. Different protective measures are taken to avoid mechanical and irradiative hazards [1–4].

The most informative and at the same time the most effective manifestations of the solar flare activity are X-ray and extreme UV solar radiation and MeV proton fluxes during Solar Proton Events (SPEs). Firstly, they increase (by several orders of magnitude) mostly during flares. Secondly, they carry the bulk of the solar activity energy.

From the very beginning of the flight, after the egress of the space vehicle from the Earth magnetosphere (at the distance of about 10 Earth's radii), the cosmonauts will undergo the influence of the high-energy solar protons and electrons that emerge during large solar flares. These bursts may be predicted from the monitoring of solar X-ray and extreme UV-radiation, as the latter reaches the Earth's orbit approximately after 8 min after the flare, whereas particles arrive with the delay of tens of minutes up to 10 h and even more. Therefore, there is some time to predict the unfavorable influence and to protect the astronauts. In SEC/SEL/NOAA [5] it was shown that the integral intensity of the flare X-ray flux at the wavelength shorter than 0,8 nm provides the best indicator for the occurrence of SPE. The duration and the brightness temperature of the flare are also important. In [6] it was found that for the X-ray flux between 0.1 nm and 0,8 nm the threshold for the SPE occurrence is ~ $2 \cdot 10^{-2}$ W/m^2.

It is apparent that the criteria of the proton flux appearance and, most importantly, the data of its intensity (with the energy exceeding 10 MeV) and spectral composition could be substantially refined if not only the above very narrow band of the X-ray spectrum, but also for the entire wavelength region of soft X-ray (to 10 nm) and extreme UV (to 120 nm) of the solar spectrum was permanent Space Solar Patrol developed in S.I. Vavilov State Optical Institute [7].

However, so far a reliable criteria of the solar cosmic rays appearance has not been discovered. This follows from ground based observation for the past 70 years of Solar Cosmic Rays with protons of maximum energy known in the physics of solar-terrestrial links as *Ground Level Enhancements or Ground Level Events (GLE)* [8]. It was found that powerful flux of relativistic particles does not mean that a powerful flux of proton will also be observed in the nonrelativistic region. GLE events account for only 15% of the total number of **large** SPEs during a solar cycle [9]. The probability that relativistic SCR reaches the Earth strongly depends on Parker spiral angle of the IMF, and the most sources are related to the ~30–90 W interval of solar longitudes (and even from behind-the-limb sources). Earlier in [10] it was shown, that the high temperature X-ray flares (especially during

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the 22nd solar cycle), including those which accompanied by the relativistic protons are localized on the East and West edges of the Sun limb.

The aim of this research is developing identification methods of the most dangerous events caused by Solar Cosmic Rays with protons with the maximum energy known in the physics of solar-terrestrial links as *Ground Level Enhancements –Events (GLEs)*. The task of the work is development of the estimation algorithm of these dangerous events probability on the basis of their correlation with the decrease of *Total Solar Irradiance (TSI)* found for the first time.

With this purpose we use phenomenon of anti-correlation between the appearance of the flux of *SCR of GLE* and the *TSI* magnitude is considered. This phenomenon was discovered recently in the State Optical Institute and seems to be of fundamental importance for the solar and solar-terrestrial physics. It occurs due to the redistribution of radiated energy between the electromagnetic and energetic corpuscular components in the solar atmosphere during periods of the relativistic (more than 500 MeV) Solar Proton Event (SPE) generations.

2. On the relations of the relativistic SCR appearance with the TSI depression

Recently, the phenomenon of correlation between the appearance on the Earth orbit of SCR of GLE and depression of TSI was discovered in the State Optical Institute [11,12].

Fig. 1 shows the registered TSI and SCR of GLE for 1983–2009 [8,13].

As we see, about 85% of the relativistic SCR events correspond to TSI decrease. **This fact allows us to propose the idea about the prediction of SCR of GLE appearance using the observed time variations of TSI.**

EUV, Wm-2 is the flux of solar radiation in the line 30.4 nm on the interval between 1995 and 2010 obtained in [14,15]. ***Vertical arrows taken from***[8] ***indicate the coincidence of GLE of SCR with the decreases of TSI***.

The explanation of detected phenomena **can be** associated with the effect of the redistribution of the radiated energy between the electromagnetic and energetic corpuscular components **of solar plasma energy during the periods of generation of relativistic fluxes of SCR**. The possibility of such effect was not previously **considered**. At the same time, the observed time variations of TSI can be explained only in less than 90% of cases [16] due to the influence of sunspots and flares. These changes occur at different time scales and associated with the appearance of the dark spots on the visible disk of the Sun (sunspot groups), or UV faculae and flocculi fields. It is worth noting interesting dual role of sunspots in the variations of the TSI [17]. Long-term changes of TSI during the cycle of the solar activity have the same sign as the changes in the number of spots: the smaller the **number of spots, the smaller is the TSI**. In contrast, short-term and well understood correlations of TSI with the passage of spots have the opposite sign. This duality shows that for an explanation of the changes of TSI it is not enough to take into account the impact of only the active regions of the solar atmosphere, there must be some additional components of the influence [17]. In [18] it is shown that the variations of UV solar radiation in the spectral region from 300 to 350 nm (~ 16%) and from 350 to 400 nm (about 26%) give the largest contribution to the changes in the value of TSI. At the same time, this radiation occurs in the UV faculae and floccular fields, but the flare increase of the soft x-ray fluxes from the entire disk of the Sun does not really contribute to the changes in TSI [16]. There is some correlation in the variations of TSI and the most common indices of solar activity: the sunspot number and radio flux at the wave 10.7 cm, but it is different for high and low activity. According to [17] this indicates on existence of an additional component of activity that is not associated directly with the given indices. For example, it was confirmed the reality of TSI decrease with decreasing magnetic activity on the Sun.

3. Events of the SCR of the GLE in October-November 2003

In [12] aggregate data of TSI and solar flare activity in October 2003 were considered. The strongest in the last decade x-ray flash occurred in that period and, as a rare case, three relativistic SCR fluxes reached the Earth, see Fig. 2.

According [19] in October-November 2003 along with loss of lock by the GPS signal there were registered following negative effects the cumulative action of the arrival of SCR and disturbances of the space weather:

1. NASA's Mars Odyssey MARIE (Martian radiation experiment) instrument failed,
2. a power system failed in Malmo, Sweden (30 October),
3. high current levels in transmission lines were observed in Wisconsin and New York.
4. Multiple satellites were affected including:

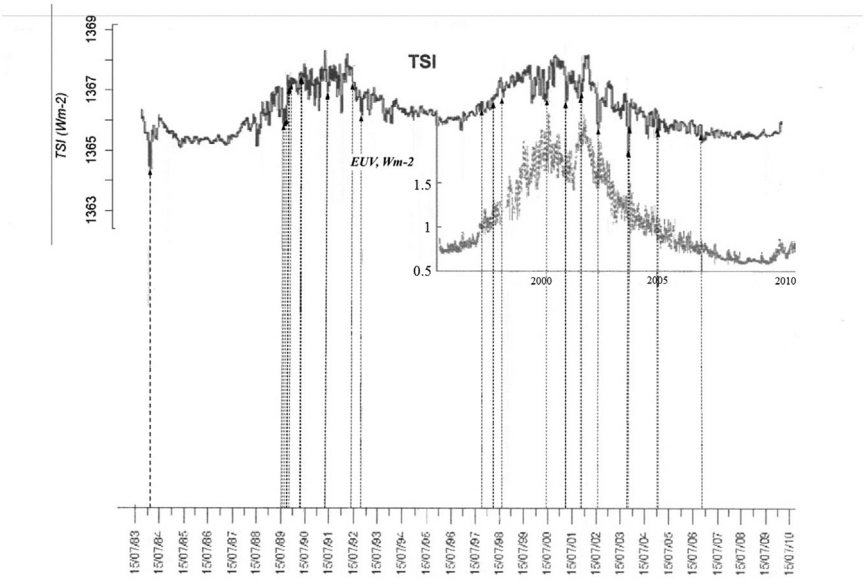

Fig. 1. TSI – Total Solar Irradiance (monthly averaged) [13].