Acta Astronautica 109 (2015) 194–202

Contents lists available at ScienceDirect

Acta Astronautica

journal homepage: www.elsevier.com/locate/actaastro

The role of a space patrol of solar X-ray radiation in the provisioning of the safety of orbital and interplanetary manned space flights

S.V. Avakyan [a,b,*], V.V. Kovalenok [c], V.P. Savinykh [d], A.S. Ivanchenkov [e], N.A. Voronin [b], A. Trchounian [f], L.A. Baranova [g]

[a] St. Petersburg State Polytechnical University, Russian Federation
[b] All-Russian Scientific Center " S.I. Vavilov State Optical Institute", St.-Petersburg, Russian Federation
[c] Federation of Cosmonautics of Russia, Moscow, Russian Federation
[d] Moscow State University of Geodesy and Cartography, Russian Federation
[e] S.P. Korolev Rocket and Space Corporation Energia, Russian Federation
[f] Yerevan State University, Armenia
[g] A.F. Ioffe Physico-Technical Institute of RAS, Russian Federation

ARTICLE INFO

Article history:
Received 10 October 2014
Accepted 17 October 2014
Available online 4 November 2014

Keywords:
Long-term manned space flight
Cosmonauts
Energetic solar protons and electrons
Human safety
X-ray and extreme UV solar radiation
Solar activity

ABSTRACT

In interplanetary flight, after large solar flares, cosmonauts are subjected to the action of energetic solar protons and electrons. These energetic particles have an especially strong effect during extravehicular activity or (in the future) during residence on the surface of Mars, when they spend an extended time there. Such particles reach the orbits of the Earth and of Mars with a delay of several hours relative to solar X-rays and UV radiation. Therefore, there is always time to predict their appearance, in particular, by means of an X-ray-UV radiometer from the apparatus complex of the Space Solar Patrol (SSP) that is being developed by the co-authors of this paper.

The paper discusses the far unexplored biophysical problem of manned flight to Mars, scheduled for the next decade. In long-term manned space flights on the orbital stations "Salyut" Soviet cosmonaut crews from three of the co-authors (cosmonauts V.V. Kovalenok, A.S. Ivanchenkov, and V.P. Savinykh) had repeatedly observed the effect of certain geophysical conditions on the psychological state of each crew. These effects coincide with the increased intensity of global illumination in the upper ionosphere space on flight altitudes (300–360 km). It is important that during all of these periods, most of the geomagnetic pulsations were completely absent. Possible ways to study the synergistic effects of the simultaneous absence of the geomagnetic field, the magnetic pulsations and the microwave radiation of the terrestrial ionosphere are considered for a flight to Mars.

1. Introduction

During space flights, the spacecraft instrumentation is exposed to the extremely negative impacts of radiation [1], but even more dangerous threats are directed to the cosmonaut crew, especially during long-term flights and in the case of future landings on the nearest celestial bodies, such as the Moon, Mars and asteroids. Because plans for manned flights to Mars are now often discussed in the scientific literature, the present paper considers important aspects of human safety during those expeditions. The experience of Russian cosmonauts obtained during long-term orbital flights is taken into account [2–7].

* Corresponding author at: St. Petersburg State Polytechnical University, Russian Federation. Tel.: +7 812 328 4791.
E-mail addresses: avak@soi.spb.ru, avakyansv@rambler.ru (S.V. Avakyan).

http://dx.doi.org/10.1016/j.actaastro.2014.10.025
0094-5765/

2. The forecasting of solar proton events by the use of space solar patrol data

In a future interplanetary flight, astronauts will be affected by high-energy solar protons and electrons at the time of large solar flares. This exposure to high-energy particles is particularly strong during a spacewalk or on the surface of the Moon and Mars (outside of the spaceship) [8]. The problems with radiation safety at the initial stage of the flight, when the effect of the radiation belts of the Earth should be taken into account, were considered in [9]. Currently, circumterrestrial manned missions are launched into orbits under the inner radiation belt (which, in the zone of the South-Atlantic and Brazilian negative magnetic anomalies, descends to the height of $\sim$600 km), where the presence of high-energy proton fluxes is unlikely. At high latitudes, where protons of solar cosmic rays may appear through polar cusps, no flights occur, either. However, a manned space flight, and even more so, a long-time flight of the International Space Station, are affected by the combined influence of factors of circumterrestrial space, which cause the degradation of some structural materials, primarily isolators, cushions, and solar batteries. In this case, a synergic effect may occur due to the overlap of the incident flux of rapid atoms of oxygen, UV and X-ray radiation of the Sun (including that in the time of a flare) and the "electron cloud", which primarily consists of high-energy photo-electrons and secondary electrons in the spells of storm precipitations from the radiation belts.

In [10], we suggested the use of the data of a permanent Space Solar Patrol (SSP) to warn spaceship crews of the occurrence of Solar Proton Events (SPEs) both at the time of the flight and after landing on surface of Mars.

X-ray and extreme UV solar radiation and MeV proton fluxes during a SPE are the most informative and at the same time the most effective manifestations of the solar flare activity. First, the radiation and proton fluxes increase the most (by several orders of magnitude) during flares. Second, the bulk of the energy of variability of the solar activity is concentrated in the radiation and proton fluxes.

From the very start of the flight, after the egress of the space vehicle from the Earth's magnetosphere (at the distance of approximately 10 Earth's radii), the astronauts will undergo the influence of 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 8 min after the flare, whereas the particles arrive with a delay of tens of minutes to 10 h and even more. Therefore, there is some time to predict the unfavorable influence and to protect the astronauts. In the case of Mars, this time is increased by a factor of 1.5 times.

Indeed, numerous data confirm the connection between X-ray radiation of the Sun during flares and the occurrence of SPE. In [11], the integral intensity of the flare X-ray flux at wavelengths shorter than 0.8 nm was found to provide the best indicator for the occurrence of SPE: if the X-ray flux for wavelengths shorter than 0.8 nm exceeds 1 W/m^2, then SPE are detected in the vicinity of the Earth in 84% of the cases. The duration and the brightness temperature of the flare are also important. In [12], the threshold for the occurrence of SPE, for the X-ray flux between 0.1 nm and 0.8 nm was found to be $\sim 2 \times 10^{-2}$ W/m^2. It is apparent that the criteria of the appearance of a proton flux, and most importantly, the data of its intensity (for the energy exceeding 10 MeV) and spectral composition could be substantially refined if the entire wavelength region of the soft X-ray (to 10 nm) and extreme UV (to 120 nm) of the solar spectrum, instead of only the above-mentioned very narrow band of the X-ray spectrum, was permanently monitored. This monitoring will be possible with the equipment of the permanent Space Solar Patrol under development at the S.I. Vavilov State Optical Institute [13].

In the first stage of the SSP space experiment, in circumterrestrial solar-synchronous orbit with the complete set of equipment, which includes the filter radiometer and the X-ray-UV diffraction spectrometers, it will be possible to obtain the spectrum of short-wavelength radiation that is specific for the appearance of SPE. Based on these data, we propose to develop a technique for the identification of dangerous situations for an interplanetary expedition using indications from a single radiometer. The size and weight of the radiometer (approximately 3 kg) will make it possible to install it on board an interplanetary space vehicle.

3. Space solar patrol methodology and apparatus

The main goal of the project titled "Creation of a Permanent Space Patrol for Extreme Ultraviolet and X-ray Solar Radiation" is the monitoring of the ionizing EUV/X-ray fluxes from the full disk Sun. This project, known as "Space Solar Patrol", is based on utilizing the known experience in the development, fabrication, and operation of radiometric and spectral optical–electronic apparatus for the measurement of the absolute ionizing solar radiation fluxes from satellites, which has accumulated at the S.I. Vavilov State Optical Institute since 1956. However, the satellites on which this apparatus was installed (the second Soviet satellite-spacecraft launched in 1960, Cosmos-262, 1968/69, and Cosmos-381, 1970/71) did not have solar orientation facilities, and the patrol measurements were found to be impossible to obtain [14]. Casual appearances of the solar disk within the field of view of both the spectral and radiometric equipment demonstrated its normal operation and reliability throughout the period of the active existence of the satellites and made it possible to obtain a number of new data on the absolute ionizing solar radiation fluxes and on the variations in their intensities during the periods of solar flares [15–20].

Permanent monitoring of the solar spectrum in the limits of this Project allows for the performance of accurate spectrophotometric measurements of ionizing radiation of solar flares, the determination of the flare classes, determination of the absolute irradiation in the UV and soft X-ray spectra, and the prediction of all cooperative phenomena of solar events related with solar flares: the formation of solar energetic protons (appearance of proton events - solar space rays), high-energy electrons, high-speed plasma streams in the solar wind, shock waves, coronal mass ejection, and, most important, the beginning of principal geomagnetic storms [14].

The space solar patrol will provide a wealth of important information on the physics of the solar atmosphere. The analysis of the state of the imbalance, ionization and excitation of the solar atmosphere can be performed by comparing data in the all spectral ranges, i.e., both soft X-ray and extreme UV radiation. These wavelengths are radiated in all areas of the atmosphere from the chromosphere to the corona of the Sun. The analysis of time dependencies of these forms of radiation provides information on the processes in these areas and the energy transfer from one area to another. Last year, the observations of the solar disk view, including a solar corona, were performed in the different spectral ranges from soft X-ray to extreme UV radiation. These observations in the different spectral ranges allow for the reliable selection of different types of flares, including limb and behind limb flares. Next, the temporal behavior of the solar ionizing radiation allows for estimation of the state of the solar atmosphere during the flares via the absorption of radiation in the solar atmosphere and, correspondingly, the geo-efficiency of a flare.

These studies are possible only through the use of permanent registration of the total spectrum of ionizing radiation of the Sun in the spectral range from X-ray to UV radiation. Only this project involves such studies. Taking into account the existence of permanent monitoring, many other characteristics of solar activity on days of the appearance of such activity via continuous collection of data for a long period of measurement provides full statistical substantiation for an analysis of the solar activity and flare events from indirect attributes, such as the flare optical ball, the type and character of radio bursts, and the solar radio flux, e.g., at a wavelength of 10.7 cm. This analysis enables estimation of long-term ground-based optical and radio–physical observations of the Sun.

The techniques of the SOI patrol measurements involve the simultaneous use of two spectrometers and a radiometer, and a special algorithm is used for separating the signals from the radiation and charged particles due to the Earth's radiation belts. In this case, the spectrometers measure a detailed source function and its variations, whereas the filter sensors provide reference information for selecting the signals of the solar radiation and for obtaining its absolute intensity, allowing for the stray light in the spectrometer (accounting for the source function and the presence of 20 wave bands isolated by foil, thin-film, and crystal filters). The signals of the radiation and the charged particles are isolated by comparing the readings from a solar sensor with those of another sensor mounted at a close pitch angle, which detects the charged particles.

Finally, all of the spectrometers and the radiometer use the same open secondary electron multipliers (modified by the State Optical Institute) based on a BeO photocathode, which is "solar-blind" and characterized by high sensitivity in the EUV and soft X-ray region. This solar-blind nature allows for the use of submicron film filters of carbon, boron, and Lexan, which are characterized by a high value of transmittance in the visible region. The multiplier has a large dynamic scope of up to 10^7. The latter characteristic enables performance of the measurements both for the quiet Sun and during the very large solar flares.

The use of the same multipliers for the entire spectral range considered enables the calibration of the absolute sensitivity of our apparatus in flight on the basis of the solar short-wave monitoring data, as described in [21].

Fig. 1 illustrates the outline of the process of measuring the absolute solar fluxes by means of the radiometer and two spectrometers of the Space Solar Patrol.

The apparatus of the permanent solar patrol system for monitoring the solar radiation is composed of the following units:

1. A space-based patrol radiometer for the spectral range of 0.14–157 nm with sequential separation of 20 bands of different spectral widths using a disk with filters made from thin metal foils, thin films, and optical crystals, as listed in Table 1.
2. A space-based patrol spectrometer for measuring the extreme UV radiation in the spectral range from 57 to 153 nm, with a spectral resolution of 1.0 nm. The spectral resolution of both spectrometers is determined by taking into account the possibility of isolation of the higher-order spectra from the most intense lines in the solar spectrum. At the same time, the spectral resolution is low enough to enable detection of a high signal from a faint solar radiation flux (in the region where the continuous spectrum or low-intensity lines dominate) against a background of the stray light in the spectrometer from the strongest lines. A 3600 grooves per mm spherical diffraction grating with a 250 mm radius of curvature, ruled on a gold layer, is used as the spectrum analyzer. This spectrometer also uses a classical arrangement of the entrance and several exit slits on the Rowland circle at their "middle" positions. The spectrum is scanned by rotating the diffraction grating through an angle of $\pm 1.9°$ relative to its middle position, with the entrance and exit slits being slightly displaced from the Rowland circle. The spectrometer is a scanning polychromator that covers a spectral range from 57 to 153 nm via three channels, each one having a bandwidth of approximately 35 nm and being equipped with its own exit slit and radiation detector.

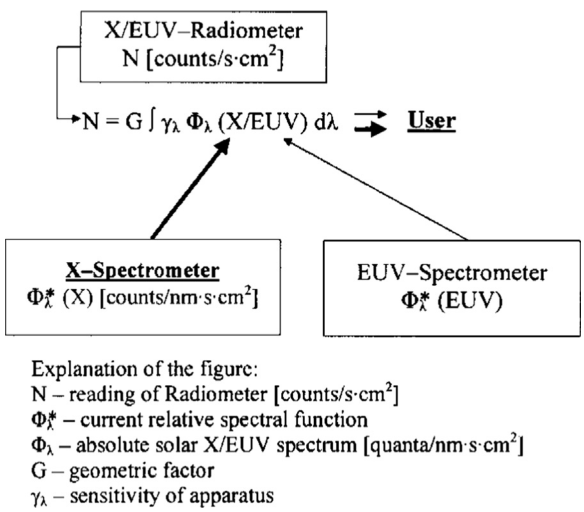

Fig. 1. Scheme for obtaining absolute flux values of X-ray/EUV radiation of the Sun via the Space Solar Patrol.

Table 1
Filters for the solar patrol radiometer.

Item no	Material	Wavelength range, nm	Thickness, μm	Size, mm	Range of solar flux measurements[a]
1	–	Calibration by Fe^{55}	–	–	–
2	–	Calibration by Fe^{55}	–	–	–
3	–	Radio signal testing	–	–	–
4	–	Zero level testing	–	–	–
5	Al-film	17–50	0.1	⌀ 0.2	5×10^{-5}–5×10^{1}
6	Cu-foil	0.14–0.25	17	4 × 6	10^{-2}–10^{4}
7	Ge-film	20–90	0.1	⌀ 0.2	5×10^{-5}–5×10^{1}
8	Ti-foil	0.25–0.43	18	4 × 6	10^{-2}–10^{4}
9	LiF-crystal	105–135	500	⌀ 0.03	2×10^{-4}–2×10^{2}
10	CaF_2-crystal	123–135	500	⌀ 0.03	3×10^{-5}–3×10^{1}
11	Be-film	11–20	0.35	⌀ 0.2	10^{-4}–10^{2}
12	Ti-foil	2.75–3.55	2	⌀ 0.3	10^{-4}–10^{+2}
13	Ti-film	31–70	0.7	⌀ 0.2	5×10^{-5}–5×10^{1}
14	C-film	4.4–7	1.3	⌀ 0.2	10^{-4}–10^{2}
15	In-film	70–103	0.2	⌀ 0.2	10^{-4}–10^{-2}
16	Be-foil	0.3–1.8	28	4 × 6	10^{-2}–10^{4}
17	Mg-film	22–60	0.2	⌀ 0.2	5×10^{-5}–5×10^{1}
18	Mg-foil	1.0–2.0	10	2 × 6	10^{-3}–10^{3}
19	SiO_2-crystal	> 157	17	4 × 6	10^{-2}–10^{4}
20	Sn-film	52–80	0.2	⌀ 0.2	5×10^{-4}–5×10^{2}
21	Al-foil	0.8–1.4	9	2 × 6	5×10^{-3}–5×10^{3}
22	LiF-crystal	105–135	500	⌀ 0.03	2×10^{-4}–2×10^{2}
23	CaF_2-crystal	123–135	500	⌀ 0.03	3×10^{-5}–3×10^{1}
24	B-film	6.6–12	0.7	⌀ 0.2	10^{-4}–10^{2}

[a] A magnitude of 10^0 corresponds to the reference solar spectrum for the mean solar activity.

In addition, three more channels are provided: two for the spectral regions of 16–34 nm and 28–63 nm to perform trials of the measuring ability of this version of the spectrometer in the given spectral range, and an auxiliary channel for the 195–230 nm spectral region to align the spectrometer under the normal atmospheric pressure conditions. In the “middle” position, the angle of incidence of the input beam is 27°, whereas the angle of the diffracted rays ranges from $-22.8°$ to 1.94° in the channels for the vacuum UV spectral region from 16 to 153 nm and amounts to 18° in the channel for the “air” spectral region of 195–230 nm. All five channels for the EUV spectral region overlap so that all of the most intense and important lines in the solar flux at 30.4 nm, 58.4 nm, and 121.6 nm are detected twice during a 72 s measuring cycle. These channels used open secondary electron multipliers (SEMs), developed at the Vavilov State Optical Institute. These multipliers are “solar blind”, i.e., insensitive to UV and visible light.

3. A space-based approach for the scanning slit-less grazing polychromatic instrument is proposed. This approach allows for the registration of the spectral distribution of the solar irradiance in the spectral range of 1.8 nm–63 nm to be performed over 72 s. A concave grating with 600 grooves per mm and with a radius $R=28080$ mm, size $S=30\times20$ mm^2, blaze angle $\delta=1°$ ($\lambda_\delta=3$ nm) is used. The variable line spacing enables the focal curve to be placed as close as possible to the exit slits. The spectral scanning is performed by means of turning the exit slit together with the detector of radiation. In this case, the entrance window and the grating are not moved. The grazing angle is 2°.

In the solar patrol equipment described here, several channels are provided for monitoring the stability of its absolute spectral sensitivity. There is a plan to perform absolute spectral calibration of the apparatus using a synchrotron radiation source prior to the period of preparation of a spacecraft for its mission. In this case, two ^{55}Fe isotope radiation sources of different intensities will be used in the radiometer in the working spectral region of approximately 0.2 nm. This method of calibration allows the variation in the absolute calibration at this wavelength to be checked after launch. An additional possibility to calibrate both the radiometer and the EUV spectrometer against the solar radiation with wavelengths longer than 150 nm appears in space. To this end, measuring the solar flux at $\lambda > 157$ nm through a quartz crystal is provided in the radiometer, and the long-wavelength measurement channel in the EUV spectrometer is capable of detecting radiation in the spectral range of up to 153 nm. In addition, the spectrometer has an auxiliary channel for the 195–230 nm spectral region, wherein the magnitude of variations in solar radiation flux does not exceed several percent during the 11-year activity cycle and the 27-day period of the rotation of the sun. However, this long-wavelength auxiliary channel enables monitoring of the stability of the diffraction grating efficiency without solar flares because the effect of space factors on a PEM-142 photomultiplier was not found at low orbits, in particular, during the Mir orbital station mission.

Finally, accounting for the success achieved to date in the patrol of the ionizing solar radiation at wavelengths shorter than 0.8 nm and longer than 120 nm, we provide a regular reference of our patrol to these data as well.

A technology procedure for producing the open secondary electron multipliers of the Vavilov State Optical Institute was developed during the period of 1960–1970. The technology was produced to obtain a proper layer of

BeO on the surfaces of dynodes and photocathode. Beryllium oxide is an effective emitter of photoelectrons and secondary electrons and maintains its properties for a long period of time during the operation under a variety of conditions of atmospheric air and incident electron flux. A 2% Be–Cu alloy was used as the original material for the manufacturing of dynodes and photocathodes. Stamped foil workpieces had a proper heat-treatment in vacuum and were then oxidized at high temperature to form a layer of BeO on the surface of dynodes [15].

The subject of the work of [13] was to measure SEM characteristics and to update the technology procedure used to produce the SEMs. Two setups were used in the vacuum chambers: a) with the X-ray monochromator [22] and b) with the radiometer [23]. The first setup covers a soft X-ray range with the following lines: $C_{K\alpha}$ (4.44 nm), $B_{K\alpha}$ (6.76 nm), $Sr_{M\xi}$ (10.865 nm), Rb (12.866 nm), $Ba_{NV\text{-}OIII}$ (16.46 nm) and $Cs_{NV\text{-}OIII}$ (19.03 nm). The absolute number of X-ray quanta on the photocathode to be investigated was measured via a proportional counter. The pulsed quantum yield of photocathodes was measured by the SEM itself according to a well-known method [24,25]. The analysis of errors indicated that relative measurements exhibit an error of 2–4% and that absolute measurements exhibit an error of 10–15% [22].

The measurements using these two setups provide the quantum yields of the photocathode made by our technology procedure over a wide spectral range; the quantum yield results are presented in Fig. 2. Note that the values of the quantum yield decrease rapidly for wavelengths greater than 100 nm. This result verifies that our SEM is insensitive to visible radiation, which has very high power in this spectral range of the Sun. The present measurements are in good agreement with the results obtained by other authors [26]; however, the quantum yield of the photocathode in the soft X-ray range is higher in our case. This discrepancy can be explained by the change in the photocathode form (we used a Γ-line photocathode) and the choice of the proper incident angle for the photon beam on the photocathode. With consideration of the entire working range of wavelengths for our apparatus, we chose an incident angle on the photocathode equal to $\sim 20^{\circ}$. For this purpose, special investigations were performed using an X-ray spectrometer.

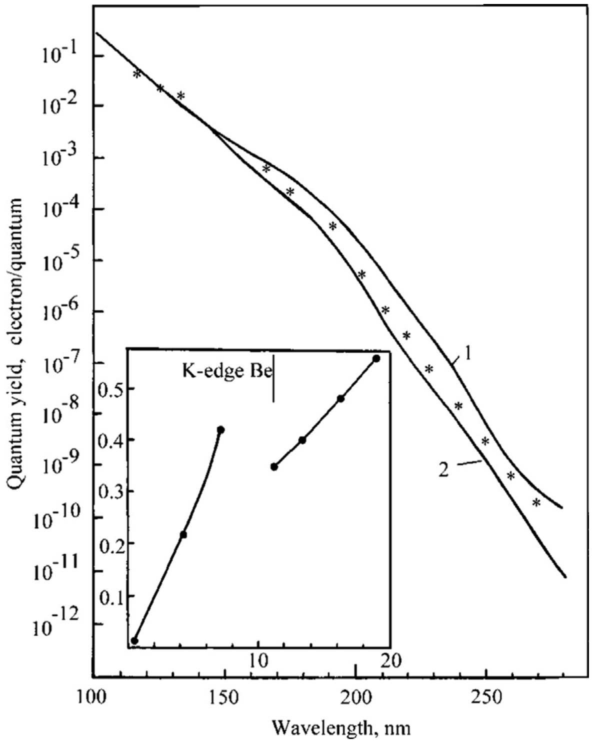

Fig. 2. Quantum yields of photocathodes from: (1) BeO obtained by oxidizing the alloy CuBeAl at $t=840$ °C and (2) BeO obtained as in the first case but with additional oxidation at $t=600$ °C. ∗ – our results at the wavelength range of 100–270 nm, ● – our results at the wavelength range of 0.2–19 nm (on the axes are the same labels).

4. Lack of geomagnetic pulsations during observation periods of the planetary glow of the ionosphere

Since the beginning of the XXI century, the focus of manned space flight is primarily on important issues related to the preparation of flights to the Moon and, most importantly, to Mars [27].

Among these concerns, most attention is on the investigation of the approaches related to the problem of life-support of a cosmonaut crew that consists of six people, based on current assumptions. The study plans for most of the duration of the flight from Earth to Mars and for the landing on Mars to assume that the crew will be separated from the module for periods exceeding one month. While the issues of radiation safety of the crew are traditionally considered as the primary part of the flight, the presence of the radiation zones as well as the destructive role of fluxes of solar energetic protons in interplanetary space flight must be taken into account. These protons are known to appear in the form of solar proton events (SPEs) after strong solar flares.

Previously a new but very important for long interplanetary expeditions problem regarding the psychophysical state of the crew in the absence of alternating electromagnetic fields and radiation, including the ionosphere one, was first raised for evolutionarily adapted humans [8]. However, to date, this subject, in particular during the long simulation experiments, such as "Mars 500", which eliminates much of their value and contribution to the Mars mission, has received almost no attention. Indeed, the results have clearly shown that the cosmonaut crews in orbital flight, even deep within the geomagnetic sphere, may experience severe psychological discomfort, the nature of which is fully defined [8]. This discomfort occurred during the appearance of such rather unusual geophysical periods of different durations (ranging from minutes to days) that were in the form of an almost complete lack of geomagnetic pulsations on Earth.

Geomagnetic pulsations (P) are the ultra-low frequency electromagnetic waves with a period of 0.2–600 s or more and are divided into stable continuous (periodic) pulsations (Pc) and irregular ones (Pi). The effect of such waves is known via a geo–biological correlation study and has strong biophysical arguments [28,29]. It is obvious to assume that due to permanent effects of the natural rhythms of the external synchronizer, i.e., those of geomagnetic pulsations, these rhythms are related to the rhythms of the electrical activity of certain brain structures. Indeed, the super slow fluctuations of potentials (SSFPs) in the brain cerebral cortex were discovered, described and studied by Aladjalova et al. [30–32]. In this case, the field of subsonic frequencies from 10^{-5} to 0.5 Hz, e.g., oscillations with a period of a few seconds to tens of minutes or hours, is coupled with the regulatory activities at different levels of the central nervous system (CNS). SSFPs are the result of the redistribution of electric charges on the cell membrane of an excited formation, thereby changing its membrane potential. These processes occur on the surfaces of opposing glial and neuronal cell membranes.

The aim of this paper is to confirm the need to consider possible pathological effects of the complete lack of rhythm formation, which is inherent to the effects of the terrestrial environment geomagnetic pulsations on the psychological and physical state of the cosmonaut crew, for the preparation and conduct of manned flights beyond the Earth's magnetosphere, particularly to Mars.

Recently, Sterlikova [29] presented new experimental data on the relationship between periods of extreme tension irritability and inappropriate behavior of patients with neurological diseases with the absence of high-frequency types of geomagnetic pulsations. The author investigated the influence of the presence of different types of geomagnetic pulsations recorded by the Geophysical Observatory “Borok” of the Joint Institute of Physics of the Earth after O. Yu. Schmidt, Russian Academy of Sciences, on the statistics of the manifestations of various diseases for Murom City, located in the same region at a distance of approximately 50 km. The period of the absence of pulsations was observed to be typical for the maximum number of events in the manifestation of the diseases, especially nervous system diseases. High-frequency pulsations of frequency similar to the basic human biorhythms were absent in 60–100% of the cases for neurasthenia and 100% of the cases for neurosis and psychosis.

One of the co-authors (cosmonaut V.V. Kovalenok), during his 140-day mission from June to November 1978, had recorded increased nervous irritability and conflict relationships between cosmonauts through the visual and instrumental observations of night emissions of the upper atmosphere of the Earth at mid-latitudes (on a planetary scale) [33,34].

It should be emphasized that the visual and instrumental studies of Soviet cosmonauts conducted during most flights on manned space crafts and orbital research stations provided an abundance of new data on various large-scale events and objects in the Earth's atmosphere and ionosphere on the surface and in the depths (up to several hundreds of meters) of the oceans [3–7,33,34]. Particularly important were the results on the impact of the factors of the increased solar–geomagnetic activity on atmospheric optical and meteorological phenomena. Registration of the variations in the upper atmosphere (ionosphere) glow and the changes in the cloud characteristics globally after such solar events, such as flares, and following geomagnetic storms provided a new interpretation of the causes of the current phase of global warming and its relation to the solar activity [35,36].

Interpretation of the results concerning observations of the optical radiation pattern in the upper atmosphere of the Earth on board the orbital manned space station “Salyut-6” indicated [5,37] that one of the unusual facts in geophysical weather, relevant to all of these cases, was the absence of geomagnetic pulsations, always 1–2 days before a change in sign of the sectors of the interplanetary magnetic field (IMF) occurred. The discovered planetary glow was interpreted as a new geophysical phenomenon-the reaction of the night upper atmosphere to ultraviolet solar flares [5,37,38].

In a personal diary, Kovalenok noted that in the period of registration of the planetary night glow of the upper atmosphere, the crew was experiencing increased excitability, which was expressed in the conflicts in radio communication with the Mission Control Center. It is certainly surprising that the sensitivity to very low levels of the amplitude of geomagnetic field variations persists, even within the metal shell space station, although there are windows. Perhaps this behavior is due to the lack of effect for the absorption of this type of pulsation in the ionosphere because the orbital station was located in the upper part of the main peak of the ionization of the ionosphere [5]. Therefore, the presence of pulsations is usually perceived by a cosmonaut's body as a stable, taken for granted, ordinary factor, while its disappearance creates the crew's discomfort. It should be emphasized that these results are consistent with a serious analysis of the notorious problem of “*unfavorable days*” [39] and confirmed to be promoted by the impact of “space weather” on the human state through a study of the reaction to geomagnetic pulsations.

Information on the observation periods of psychophysical instability and the presence or, more typically, a lack of geomagnetic pulsations is presented in Table 2 [8]. Table 2 also presents the main characteristics of the pulses [40]: the period (frequency) and amplitude. The information about the manifestation of geomagnetic pulsations in Table 2 was obtained by measurements of the Geophysical Observatory “Borok”. In the first six dates (see Table 2), cosmonauts Kovalenok, Ivanchenkov, and Savinykh recorded in such cases the “planetary glow of the second emissive layer,” i.e., emissive radiation of the night F-region of the Earth-bound ionosphere at the time, in the mentioned periods. The four events are tied to the time on the basis of the data of the strong emission light of the night F-region (the red *emission* of the oxygen atom-630 nm); according to the Abastumani Astrophysical Observatory, Georgian Academy of Sciences (Georgia) [38], the cosmonauts in the period from the 6th to the 9th of July, 1978, observed a “planetary glow” at almost every turn (to its dark side).

Table 2 shows the information regarding the four types of geomagnetic pulsations of the following considerations. Ripple Pi1C, similar to all irregular pulses, usually characterizes periods of geomagnetic disturbance. However, in times of global emission monitoring by cosmonauts, its visual pattern was radically different from the pictures of auroras, which could also be observed on the middle and lower latitudes; however, this observation was performed

Table 2
Geomagnetic pulsations during the observation periods for the phenomenon of the reaction of the night upper ionosphere to solar flares [8].

		Irregular	Continuous (periodic)		
		Pi1C	Pc2	Pc3	Pc4
Frequency, Hz		More than 1	$2\times10-1\div6\times10-2$	$6\div2\times10-2$	$2\times10-2\div6\times10-3$
Period, second		$1\div40$	$5\div15$	$15\div45$	$45\div150$
Amplitude, 10-5E		0.02	0.6	0.6	up 10
Date	Time, UT	Pulsation's recorded by geophysical observatory “Borok”			
14.08.78	00.45–00.50	Very weak Pi1C	No	Yes	No
16.09.78	20.00–03.00	No	No	From 00.40–yes	No
28.10.78	20.30–21.16	No	No	No	No
28.10.78	22.44	No	No	No	No
03.05.81	00.38	No	No	No	No
03.05.81	15.52–15.56	No	No	No	No
06.07.78	23.30–01.00	No	No	Yes	No
07.07.78	18.00–20.30	No	No	No	No
08.07.78	20.00–22.30	No	No	No	No
09.07.78	18.20–20.10	No	No	No	No

during strong geomagnetic storms [3–5,7]. Avakyan et al. [5] examined in detail the characteristics, according to (Ref. [41]), of the observed glow of the red emission of 630 nm with the appearance of the class Pi1C oscillations. This glow was not observed for the dates covered in Table 1. Therefore, the phenomenon of “planetary glow of the second emissive layer” is different from the nature of auroras. The remaining ripple Pc2 - Pc4 are of a stable type and usually regularly recorded.

It follows from Table 2 that over the observation period (such as the periods of “planetary glow” and the periods of increased conflict among cosmonauts), there were no recorded geomagnetic fluctuations of the stable type or irregular ones.

An important factor to ensure the adequate results for the allocated special periods in geophysical weather (without pulsation of Pi1C type, according to the Geophysical observatory “Borok”) is that the observations of planetary glow of the upper ionosphere (i.e., it describes the pattern of the reaction night-time ionosphere to solar flares [5,37,38]) by the station “Salyut-6” are usually performed at night in the Borok time zone (Table 2). As a result, the observed lack of Pi1C is quite an unusual phenomenon because this type of daily maximum ripple falls exactly on 23.00–1.00 UT.

Earlier, Nikolaev et al. [42] proposed a hypothesis regarding the decisive role of the disappearance of geomagnetic pulsations (short-period variations of the geomagnetic field), especially Pc2 - Pc4, with periods ranging from 5 to 150 s, in disorders of human CNS. Another point of emphasis is the special influence of polarity changes in IMF sectors (most of all, under the change from a negative polarity to a positive one) was marked experimentally. To explain this phenomenon, it is proposed to take into account that the patient's (and in our opinion, in the case of space flight, a cosmonaut subjected to stress, gravity and other factors) body needs almost constant exposure to the electromagnetic field quasi sinusoidal oscillations of a certain frequency from external sources to synchronize the operation of its various systems [42]. Therefore, such external factors may affect the geomagnetic field, sometimes disappearing all over the Earth simultaneously [42].

In general, the natural electromagnetic field of the Earth is an entire spectrum of electromagnetic “noise” covering a wide frequency range from 10^{-3} Hz to 10^{9} Hz [40]. Recently, attention was drawn to the higher frequency range, the microwave radiation of the ionosphere [43,44]. Because of the existence of wave motions in the upper atmosphere in the form of acoustic-gravity and infrasound waves, this radiation of the ionosphere is modulated in amplitude just in subsonic frequencies, from 10^{-5} Hz to a few Hz, in the area of the SSFP in the brain cerebral cortex [30–32]. Thus, the background of electromagnetic waves that always exists on the surface of the Earth is generated by several sources. Among these sources are micro-pulsations of the geomagnetic field, very-low-frequency (VLF) radiation of the magnetosphere and ionosphere, and atmospherics (low-frequency part of the spectrum of lightning charges). The oscillation amplitude (field intensity) is maximal in the VLF range (less than 5 Hz), where the magnetic component is usually recorded as short-period variations of the geomagnetic field (micro-pulsations). These micro-pulsations as well as the fluctuations in the high frequencies (kHz) are generated in the magnetosphere or on its border.

Different types of pulses mainly appear at certain times of day. In times of disturbances (magnetic storms), excitations of global micro-pulsations are observed and can be recorded during dozens of hours in a row around the Earth. The top of the storm is preceded by the appearance of oscillations in the band Pc1-called pearl. The main frequency of 3 ± 0.3 Hz for these oscillations is amplitude-modulated with a period of 2–5 min.

All of these electromagnetic waves are usually the background for the earthling to escape with the travel of the interplanetary spacecraft beyond the magnetosphere, and after a few days of flight, the cosmonauts will be out of the usual electromagnetic “noise”, as well as outside of the geomagnetic field. As shown in (Ref. [45]), the hypogeomagnetic field also affects humans. The person may feel pain as the impact of 1000 times the weakened field, as well as an increased amount of pain at approximately the same time. It is unknown, however, if the simultaneous absence of the geomagnetic field and electromagnetic waves over a wide range of frequencies, from low (including in the field of brain rhythms, heart, etc.), to the highest including the extremely high frequencies, affects the human organism due to resonance effects in the cells of the body [43,44]. Therefore, in the coming years, during the preparatory stages of the first interplanetary flight, the study must be performed on the synergistic effects of exposure to the fields on humans under the expected absence of the usual "sets" of oscillations of electromagnetic fields, especially geomagnetic pulsations, when the real background of a hypo-magnetic field exists.

The problem of Mars missions and stay at the planet [47] need thorough investigation of geomagnetic effects on humans and comparing it with Mars environment. It should be emphasized that the flights and landings on the Moon cannot be analogous to the situation considered above, as those flights continued outside the magnetosphere of the Earth for less than a week. Most importantly, the Moon during each lunar month (29 days) is trailing the geomagnetic sphere for several days.

5. Conclusion

This paper discussed the primary issues for ensuring the safety of manned flights to Mars:

– total monitoring of the flux level and of the character of the spectrum of solar short-wavelength activity, including the use of a compact X-ray-UV radiometer, such as the one used in the complex of the Space Solar Patrol apparatus, installed directly on board the interplanetary space ship;
– a study of the situation in which there is no natural electromagnetic "noise" on the background of geomagnetic fields, especially the geomagnetic pulsations that have accompanied human evolution.

The core of the study is the situation of the psychological state of the crew of cosmonauts when there is completely no natural electromagnetic "noise", which has accompanied the entire evolution of mankind. A part of the study can be realized on the International Space Station by the same scenario as in the observation made by the orbital manned space station "Salyut-6" [8]. This study can be performed, for example, in the framework of the European Space Agency – "Roscosmos" Agency Joint Program, as the detection and study of the potential hazards for interplanetary flight. The study should use just the technique of visual detection of an elevated emission of the upper atmosphere on a global scale [5]. The rest of the program will require a special experimental study with the construction of a chamber with a hypo-magnetic field while shielding the microwave radiation generated in the Earth's ionosphere [43,44,46]. Technical solutions for these problems could be developed in the institutions of the National Academy of Science of the Republic of Armenia.

Acknowledgments

The authors are grateful to the foreign partners of the project: Dr. G. Schmidtke, Dr. N. Pailer (Germany), Dr. A. Aylword (UK), Dr. J.-P. Delaboudinier (France) and Dr. Uk-Won Nam (Korea). This work was supported in the resolutions of the Second International Symposium on the Thermospheric, Ionospheric, and Geospheric Research (TIGER Program), 1999, St. Petersburg, Russia, and the General Assembly of the International Association for Geomagnetism and Aeronomy, as well as at the General Assemblies of COSPAR, Commission C ("Space studies of the upper atmospheres of the Earth and planets"), Commission D ("Space plasmas in the solar system), and Commission E ("Research in astrophysics from space"), and URSI (International Union of Radio Science), Scientific Commission G ("Ionospheric Radio and Propagation"). The authors are also grateful to the professor, correspondent-member of the Russian Academy of Science M.V. Silnikov - director of the Institute of Military Engineering and Safety Research at St. Petersburg State Polytechnical University.

References

[1] M.V. Silnikov, A.I. Mikhaylin, Protection of flying vehicles against blast loads, Acta Astronaut. 97 (1) (2014) 30–37.
[2] A.I. Lazarev, V.V. Kovalenok, V.P. Savinykh, Visual-instrumental Observations With Salyut 6, Gidrometeoizdat, Leningrad, 1983.
[3] A.I. Lazarev, V.V. Kovalenok, A.S. Ivantchenkov, S.V. Avakyan, Atmosphere of Earth From "Saluyt-6", Gidrometeoizdat, Leningrad, 1981, 207.
[4] S.V. Avakyan, V.I. Drobzev, V.M. Krasnov, G.S. Kudrjashev, A.I. Lazarev, A.G. Nikolaev, V.I. Sevastjanov, A.F. Yakovets, in: S.V. Avakyan, V. M. Krasnov, A.I. Lazarev (Eds.), Waves and Emissions of the Upper Atmosphere, Nauka, Alma-Ata, 1981, p. 170.
[5] S.V. Avakyan, V.V. Kovalenok, N.F. Solonitsina, in: S.V. Avakyan (Ed.), Night F-Region of the Ionosphere During the Solar Flares, Nauka, Alma-Ata, 1984, p. 150.
[6] A.I. Lazarev, V.V. Kovalenok, S.V. Avakyan, Investigation of Earth from Manned Spacecrafts, Gidrometeoizdat, Leningrad, 1987, 399.
[7] S.V. Avakyan, L.S. Yevlashin, V.V. Kovalenok, A.I. Lazarev, V.G. Titov, Observation of Aurora from Space, Gidrometeoizdat, Leningrad, 1991, 229.
[8] V.V. Kovalenok, S.V. Avakyan, O.K. Borovkova, N.A. Voronin, Space solar patrols and some problems of manned flight to Mars, J. Opt. Technol. 72 (8) (2005) 615–619.
[9] V.M. Petrov, Features of the development of radiation norms for manned expedition to Mars, in: Abstracts of International Conference on Systems and Technologies for Future Exploration and Development of Space, Moscow, 2003, pp. 39–40.
[10] S.V. Avakyan, I.M. Afanas'ev, N.A. Voronin, A.V. Savushkin, Progress in the creating of the space solar patrol apparatus within the frames of ISTC projects, in: Abstracts of International Conference on Systems and Technologies for Future Exploration and Development of Space, Moscow, 2003, pp. 103–104.
[11] H.A. Garcia, Temperature and hard X-ray signatures for energetic proton events, Astrophys. J. 420 (1) (1994) 422–432.
[12] Y. Kubo, M. Akioka, Existence of thresholds in proton flares and application to solar energetic particle alerts, Space Weather, vol. 2, 2004, S01002, 5 p.
[13] Avakyan S.V., Andreev E.P., Afanas'ev I.M., Leonov N.B., Savushkin A. V., Serova A.E., Voronin N.A., Creating of the permanent space patrol of ionizing solar radiation, in: S.L. Keil, S.V. Avakyan (Eds.) Innovative Telescopes and Instrumentation for Solar Astrophysics, Proceedings of SPIE, vol. 4853, 2002, pp. 600–611.
[14] S.V. Avakyan, N.A. Voronin, A.I. Efremov, et al., Methodology and equipment for space-based monitoring of ionizing solar radiation, J. Opt. Technol. 65 (12) (1998) 124–131.
[15] A.I. Yefremov, A.L. Podmoshenskii, O.N. Efimov, A.A. Lebedev, Study of the short wave solar radiation, Artif. Earth Satell. 10 (1961) 3–11.
[16] A.I. Yefremov, A.L. Podmoshenski, M.A. Ivanov, V.N. Nikiforov, O.N. Yefimov, Filter devices for study of the short wave solar radiation, Artif. Earth Satell. 10 (1961) 48–54.
[17] A.I. Yefremov, A.L. Podmoshenski, O.N. Yefimov, A.A. Lebedev, Investigations of solar x rays and L alpha radiation on August 19–20, 1960, Space Res. 3 (1963) 843.

[18] A.I. Yefremov, S.V. Avakyan, A.L. Podmoshenski, M.P. Bolgartseva, L.N. Gershun, I.M. Pribylovski, M.A. Ivanov, V.S. Petrov and G.V. Sazonov, Absolute radiation fluxes from the quiet Sun in the spectral range from 0.45 to 121.6 nm, in: Proceedings of the Investigations in Geomagnetic Aeronomy and Solar Physics Conference, vol. 32, Moscow, 1974, pp. 162–164.
[19] A.I. Yefremov, S.V. Avakyan, A.L. Podmoshenskii, I.M. Pribylovski, M. A. Ivanov, V.S. Petrov and G.V. Sazonov, Radiation Fluxes from the quiet Sun in the spectral range from 0.45 to 121.6 nm, Prepnnt IZMIRAN, Academy of Sciences of the USSR, Moscow, 1973.
[20] S.V. Avakyan, M.P. Bolgartseva, L.N. Gershun, A.I. Yefremov, Y.u. V. Kushnerevskii, L.N. Leshchenko, I.N. Odintsova, V.S. Petrov, A.L. Podmoshenskii, G.V. Sazonov, Ionizing solar radiation according to the data from the Kosmos 381 satellite and its effect on the ionosphere, Geomagn. Aeron. 13 (1973) 922.
[21] G. Schmidtke, B. Nikutowski, C. Jacobi, R. Brunner, C. Erhardt, S. Knecht, J. Scherle, J. Schlagenhauf, Solar EUV irradiance measurements by the auto-calibrating EUV spectrometers (SolACES) aboard the International Space Station (ISS), Sol. Phys. 289 (5) (2014) 1863–1883, http://dx.doi.org/10.1007/s11207-013-0430-5.
[22] E.P. Savinov, I.N. Tschemelev, Outside X-ray photoeffect statistics of bulky photocathodes, J. Exp. Theor. Phys. 60 (4) (1971) 1371–1378.
[23] S.V. Avakyan, S.V. Murashov, I.M. Pribilovsky, G.V. Sazonov, A.I. Yefremov, L.D. Fedotov, M.I. Kislitsky, A.P. Moshkanchev, B.I. Poletaev, V.I. Sapozhnikov, System of space patrol of solar ionizing radiation, in: Hiroyuki Fujisada, Guido Calamai, Martin N. Sweeting (Eds.), Advanced and Next-Generation Satellites II, Proceedings of SPIE, 2957, 1996, pp. 230–241.
[24] A.M. Tutikov, On secondary electron multiplier working in pulse counting regime, Devices Methodol. Exp. (1) (1962) 154–157.
[25] A.P. Lukirsky, E.P. Savinov, I.A. Britov, Y.u.F. Tschepelev, Efficiency of SEM with photocathodes Au, LiF, MgF_2, SrF_2, BeO, KCl, and CsJ in the region of wavelength 23.6–113 Å, Trans. USSR Acad. Sci. Phys. Dep. 28 (5) (1964) 866–871.
[26] E.P. Savinov, A.P. Lukirsky, Efficiency of SEM with photocathodes Au, Ni, LiF, MgF2, SrF2, CsJ, KCl, and BeO in the region of wavelength 75–300 Å, Opt. Spectrosc. J. 23 (2) (1967) 303–307.
[27] Systems and technologies for future exploration and development of space, International Conference, Abstracts,Moscow, ISTC, 2003.
[28] V.N. Bingi, Magnetobiology: Experiments and Models, IOF RAN, Moscow, 2002.
[29] I.V. Sterlikova, Research of influence of the corpuscular agent of solar activity on the human organism, Fundam. Res. Phys. Math. Sci. 11 (2002) 715–721.
[30] N.A. Aladjalova (Moscow), Slow Electrical Processes in the Brain, , 1962 (USSR Academy of Sciences).
[31] N.A., Aladjalova, Super slow rhythmic processes in the nervous system, in: Continuous Potentials of the Nervous System, Tbilisi, 1969.
[32] N.A. Aladjalova, Psychophysiological Aspects of Brain Super Slow Rhythmical Activity, Nauka, Moscow, 1979.
[33] V.V. Kovalenok, S.V. Avakyan, The colours of space, Space, FTI, Leningrad, 1987.
[34] Avakyan, S.V., A new factor in the physics of solar-terrestrial relationships – the Rydberg states of atoms and molecules, in: Proceedings of the Representative International Conference on Physics of Solar-Terrestrial Relationships, Almaty, 1994, pp. 3–5.
[35] S.V. Avakyan, N.A. Voronin, On the radiooptical and optical mechanisms of influence of cosmic factors on the global warming, J. Opt. Technol. 77 (2010) 141–144.
[36] S.V. Avakyan, N.A. Voronin, The role of space and ionospheric disturbances in the global climate change and pipeline corrosion, Proc. SPIE: Atmos. Ocean Phys. 47 (2011) 1143–1158.
[37] S.V. Avakyan, Investigations of heliogeophysical disturbances under nocturnal conditions from manned spacecraft, J. Opt. Technol. 64 (1997) 940–945.
[38] S.V. Avakyan, G.S. Kudryashev, L.M. Fishkova, Concerning the amplification of the O I 630-nm emission of luminescence of the sky during solar flares, Geomagn. Ae´ron. 25 (1985) 415–419.
[39] S.I. Avdyushin, A.D. Danilov, An Account of Space Weather, Gidrometeoizdat, Leningrad, 1993.
[40] M.I. Pudovkin, O.M. Raspopov, N.G. Kleimenova, Perturbations of the Earth's Magnetic Field, Leningrad State University Press, Leningrad, 1976 (Chapter 4).
[41] O.K. Borovkova, Yu E. Borovkov, V.A. Troitskaya, On the connection of the amplification of the 6300 Å emission in middle latitudes with geomagnetic pulsations, Geomagn. Ae´ron. 23 (1983) 494–496.
[42] Yu S. Nikolaev, J.J. Rudakov, S.M. Mansurov, L.G. Mansurova, Interplanetary magnetic field sector structure and disturbances of central nervous system activity, Probl. Space Biol. 43 (1982) 51–59.
[43] S.V. Avakyan, Microwave radiation of the ionosphere as a factor in the way solar flares and geomagnetic storms act on biosystems, J. Opt. Technol. 72 (2005) 608–614.
[44] S.V. Avakyan, Microwave ionospheric emission as a new factor of solar-biosphere relations, in: Proceedings of the 4th International Workshop on Biological Effects of Electromagnetic Fields, Crete, vol. 2,2006, pp. 1513–1522.
[45] Yu A. Kholodov, N.N. Lebedeva, in: M.G. Ayrapetyants (Ed.), Electromagnetic Biology, Nauka, Moscow, 1992.
[46] B.E. Gel'fand, M.V. Sil'nikov, A.I. Mikhailin, A.V. Orlov, Attenuation of blast overpressures from liquid in an elastic shell, Combust. Explos. Shock Waves 37 (5) (2001) 607–612.
[47] M. Smirnova, Mars transportation vehicle concept, Acta Astronaut. 103 (2014) 250–256.