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Abstract

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PRELIMINARY RESULTS OF A STUDY OF THE SUN' S X-RADIATION BY MEANS OF ROCKETS AND SPACECRAFT

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This communication briefly sets forth preliminary results of investigations of the Sun' s X-radiation in the spectral region shorter than 10 Å, carried out during two vertical launches of geophysical rockets to an altitude of 105 km on 21 VII 1959 and during the flights of the second and third spacecraft on 19–20 VIII (perigee altitude 305 km, apogee 320 km) and 1–2 XII 1960 (perigee altitude 180 km, apogee 249 km).

The study of the Sun' s short-wavelength radiation, which is absorbed by the terrestrial atmosphere, is of considerable interest for many problems of solar physics and geophysics. Of particular importance is the study of the short-wavelength edge of the solar spectrum, extending to the region of several angstroms. This radiation comes from the hottest regions of the solar corona and is subject to rapid changes connected with the dynamics of as yet unexplained physical processes occurring in the outer envelopes of the Sun; it also penetrates most deeply into the Earth' s atmosphere and plays an essential role in the formation of the lower layers of the ionosphere. A theoretical investigation of the Sun' s short-wavelength radiation was carried out by I. S. Shklovskii (^1), and later by De Jager and Elwert (^2), T. V. Kazachevskaya and G. S. Ivanov-Kholodnyi (^3).

Experimental studies of the Sun' s X-radiation have been carried out with rockets during the last decade in the U.S.A. by H. Friedman and collaborators (^4). The experimental material obtained up to the present time is, naturally, comparatively small; further systematic investigation of this radiation by means of rockets and, in particular, satellites, which make it possible to study variations of the radiation with time, appears necessary.

In the apparatus installed by us on the rockets, the radiation receivers were Geiger end-window photon counters with a mica window (1.6 mg/cm^2, $d = 4$ mm) and an evaporated aluminum layer about 2 μ thick. The counters were placed outside the instrument container, which oriented itself toward the Sun after separation from the rocket. For protection against low-energy electrons, which could produce bremsstrahlung X-radiation at the entrance windows of the

Figure 1

Figure 1: Figure 1

Figure 2

Figure 2: Figure 2

counters, there was a magnetic system preventing bombardment of the windows by electrons with energies of 15-20 keV, as well as control counters.

The pulses from the counters were fed to two scaling systems; the counting rate was transmitted to Earth by a telemetric system. The launches were carried out in the morning and evening; in both experiments the zenith distance of the Sun was about 90°.

A noticeable increase in the counting rate of the counters directed at the Sun was registered beginning at an altitude of 95 km; in both cases the control counters showed the absence of a noticeable number of electrons. This makes it possible

attribute the recorded radiation to the X-ray radiation of the Sun.

Figure 1 shows the readings of the working and control counters in the second launch; in this experiment the control counter was turned away from the Sun by 15°. The second small maximum in the counting rate corresponds to the maximum of the cosmic background.

On the basis of V. V. Mikhnevich' s data on the distribution of atmospheric density with altitude ([5]), the measurement results were extrapolated to the boundary of the atmosphere. The obtained values of the radiation flux in the 2-10 Å region are $7.3 \cdot 10^{-4}$ and $3.2 \cdot 10^{-4}$ erg/cm$^2 \cdot$ s. During the launch of the second rocket

Fig. 1. Counting rate N as a function of time after the rocket launch: *a*—readings of the counter directed at the Sun; *b*—readings of the control counter

Fig. 2. Portion of the recording of the readings of counters with beryllium windows, obtained on 20 VIII 1960 on the second spacecraft. Moscow time

a class I chromospheric flare was observed. The experimentally observed change in radiation intensity with altitude is satisfactorily approximated if it is assumed that the Sun' s radiation in the spectral region 2-10 Å is continuous and has a bremsstrahlung character with a temperature of $4.5 \cdot 10^6$ °K.

In the apparatus installed on the second spacecraft, the main radiation receivers were six end-window photon counters covered with beryllium windows 0.1 mm thick (window diameter 7 mm). The counters were installed in the instrument compartment in six mutually perpendicular directions; the half-width of the field of view of each counter was about 25°. The counter windows had magnetic shielding. Pulses from the counters were fed to the input of a common

Fig. 3. Section of the record of readings obtained on 1 XII 1960 on the third spacecraft: a –readings of mica counters directed toward the Sun; b –readings of control mica counters; c –readings of beryllium counters (all data are in counts/sec per counter). Moscow time

Figure 3: Fig. 3. Section of the record of readings obtained on 1 XII 1960 on the third spacecraft: a –readings of mica counters directed toward the Sun; b –readings of control mica counters; c –readings of beryllium counters (all data are in counts/sec per counter). Moscow time

counting circuit, the states of the last cells of which were read every 3 min by a storage device. The readings of this device for 13 revolutions of the spacecraft were transmitted to Earth by the telemetry system. In addition, the counting rate was transmitted directly by the telemetry system during periods of radio communication with Earth.

Figure 2 presents a portion of the storage-system record. At the bottom are marked the intervals during which the spacecraft was in the Earth' s shadow.

On the sunlit side of the orbit the counters record considerable radiation, producing a counting rate of the order of several thousand pulses per second; on the shadow side of the orbit the counting rate decreases to several tens of pulses per second, characterizing the cosmic background. The stepwise character of the record on the sunlit side is caused by the Sun leaving the fields of view of the counters.

Regions of high counting rate partially extend onto the shadow side of the orbit. These portions of the orbit are located mainly at latitudes where, in the works of S. N. Vernov, A. E. Chudakov, and J. A. Van Allen, protrusions of the outer radiation belt were found ([6]). It is natural to assume that the larg–

···a higher counting rate on the shadowed portions of the orbit was caused by bremsstrahlung of electrons and by fast penetrating particles. It is rather difficult to separate the contribution of the Sun' s X-ray radiation from the action of particles on the sunlit side of the orbit in the region of high and middle latitudes. As for the region of low latitudes, analysis of the records on the shadowed side of the orbit shows that, at the altitude of the spacecraft' s orbit, the radiation due to the radiation belts does not extend below 30—40° north and 20—30° south latitude. It may be assumed, as was confirmed by subsequent experiments on the third spacecraft, that the same is true for the sunlit side of the orbit as well. The counter readings in the latitude region below 20—30° may therefore for the most part be ascribed to the Sun' s X-ray radiation*. For the radiation flux in the range 2—10 Å, a value of $7.6 \cdot 10^{-4}$ erg/cm^2 · sec is obtained.

Fig. 3. Section of the record of readings obtained on 1 XII 1960 on the third spacecraft: **a** –readings of mica counters directed toward the Sun; **b** –readings of control mica counters; **c** –readings of beryllium counters (all data are in counts/sec per counter). Moscow time.

Changes were introduced into the apparatus installed on the third spacecraft: two counters with a mica window (1.6 mg/cm^2, $d = 4$ mm), covered by two layers of aluminum foil 5 μ thick and connected in parallel, were mounted on the system of solar batteries of the spacecraft that automatically oriented itself toward the Sun—their axes were thus directed toward the Sun at all times. Two similar counters were placed on this system with their axes directed perpendicular to the direction toward the Sun; in front of the windows of these counters there was a tantalum plate inclined at an angle of 45° to the direction toward the Sun and to the axes of the counters. These control counters evidently registered only the X-ray radiation arising from the braking of electrons on the tantalum plate, and thus made it possible to identify sections of the orbit with a noticeable background from electrons. In the instrument compartment two counters with a beryllium window 0.1 mm thick were installed, with axes parallel and connected in parallel; the counters had magnetic shielding. The counting circuit and the recording of pulses on the storage device remained as before and consisted of three independent channels.

Figure 3 shows a section of the records. The character of the record of the counters directed toward the Sun is the same as before—the main radiation is concentrated on the sunlit side of the orbit; however, significant radiation is also partly present in the region of shadow. Guided by the readings of the control counters, it is possible to exclude sections of the record of the counters directed toward the Sun, and of the counters in the instrument compartment, in which electron interference is strong. The radiation recorded on sections of the orbit free from these interferences is due to the Sun's X-ray radiation. The presence of gaps in the record of counter **c**, following the Sun, was caused, as a comparison showed,

* The absence of a noticeable background from electrons in the low-latitude region is also confirmed by the fact that, in some sections of the record of direct transmission on the sunlit side of the orbit, the counting rate, when the Sun left the field of view of the counters, fell to the level of the cosmic background.

these portions with the recording of the current of the solar batteries, by a temporary eclipse of the system. Separate maxima of the counting rate, obtained in the region of low latitudes on the sunward side of the orbit for the counters installed on the instrument compartment, correspond to the Sun being within the field of view of these counters. From the maximum counting rate of the counters with beryllium windows, the value of the flux of X-ray radiation in the region 2—10 Å is obtained as $2.4 \cdot 10^{-4}$ erg/cm$^2 \cdot$ sec. Comparison of the readings of both

Fig. 4. Orientation map of regions of appreciable corpuscular radiation according to the data of the control mica counters of the third spacecraft. The numbers on the curves are counting rates in pulses/sec per counter

types of counters gives, for the electron temperature of the Sun' s radiation in this region of the spectrum, a value $\sim 2 \cdot 10^6$, under the assumption that the

Fig. 4. Orientation map of regions of appreciable corpuscular radiation according to the data of the control mica counters of the third spacecraft. The numbers on the curves are counting rates in pulses/sec per counter

Figure 4: Fig. 4. Orientation map of regions of appreciable corpuscular radiation according to the data of the control mica counters of the third spacecraft. The numbers on the curves are counting rates in pulses/sec per counter

radiation is of bremsstrahlung character. Throughout the entire duration of the measurements the flux of X-ray radiation remained very constant.

It should be borne in mind that the absolute energy estimates given above are approximate, valid within a possible error of the order of a factor of 2—3. The results of our measurements are in good agreement with the measurements of H. Friedman, carried out over the course of a full solar cycle; for the region shorter than 8 Å he obtained values lying between $3 \cdot 10^{-6}$ and $1.5 \cdot 10^{-3}$ erg/cm$^2 \cdot$ sec.

In Fig. 4, regions of appreciable quantities of electrons, constructed on the basis of the readings of the control mica counters, are plotted on the map. As already indicated, these regions descend to latitudes of 20—30°. There is an anomaly lying in the region 35—50° S in latitude and 30° W-20° E in longitude, also observed in the work of L. V. Kurnosova et al. (7). The boundaries of the regions corresponding to different levels of particle counting are very conditional and probably not constant in time.

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Note: Figure translations are in progress. See original paper for figures.