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OBSERVATIONS OF SCATTERED L_α-EMISSION IN THE VICINITY OF THE EARTH AND IN THE INTERPLANETARY MEDIUM

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ABSTRACT

Measurements of ultraviolet emission in two bands: λ 1050 - 1340 A and 1225 - 1340 A have been conducted on AIS "VENERA-2" and "VENERA-3", respectively launched on 12 and 16 November 1965. By the emission intensity in the first band, including the line L_α(λ 1216 A) the density was computed of atomic hydrogen near the Earth and to 20 R_E (Venera-2) and to 7 R_E (Venera-3). At the distance of 5 R_E the density was 25 cm^{-3}. At great distances from the Earth the concentration of neutral hydrogen decreases proportionally to $R^{-2.1}$ and $R^{-2.3}$. The measured density was found to be in good agreement with the data of preceding measurements on AIS "ZOND-1".

In the interplanetary medium, far from Earth, the intensity of L_α-emission is $7 \cdot 10^{-5}$ erg/cm²·sec·ster, which corresponds to the density of neutral component of the interplanetary medium $\sim 3 \cdot 10^{-3} cm^{-3}$ for the "hot" interplanetary gas model. In the course of the measurement period from November 1965 to January 1966 the intensity remained constant with a precision to ∿ 30 percent. A systematic slow intensity increase by about 20 to 30 percent was observed as the AIS approached the Sun. During chromospheric flares of force 2 no intensity increase of the scattered L_α-emission was observed. Nor was any correlation observed with the areas of calcium flocculi and spots on the Sun's disk.

The counter, sensitive in the band λ 1225 - 1340 A, registered the background linked with cosmic rays, whereupon the intensity of ultraviolet emission did not exceed 10^{-7} erg/cm²·sec·sterad.

*

* *

Two-channel ultraviolet photometers have been installed aboard interplanetary stations (AIS) "Venera-2" and "Venera-3" with the view of registering the scattered L_α-emission.

(*) NABLYUDENIYA RASSEYANNOGO L -IZLUCHENIYA V OKRESNOSTYAKH ZEMLI I V MEZHPLANETNOY SREDE.

Both AIS were launched in the direction to Venus and moved along about the same orbits. The launching of AIS Venera-2 took place on the 12th and that of Venera-3 on 16 November 1965.

The installed devices were identical to those earlier described in the works on the results of investigations by means of geophysical rockets [1] and of AIS "Zond-1" [2]. Two SFM-1-type photon Geiger counters were parts of the each device's assembly with windows made of lithium fluoride and sensitive in the band 1050 - 1340 A. An additional calcium fluoride filter was installed ahead of one of the counters. The data relative to the devices are compiled in Table 1 hereafter.

TABLE 1

Characteristic	"VENERA-2"		"VENERA-3"	
	1st channel	2nd channel	1st channel	2nd channel
Response region, A	1050 – 1340	1050 – 1340	1050 – 1340	1225 – 1340
Grid transm. in %	30	100	30	100
Field of Vision, °	7	7	7	20
Counter's quantum yield at λ 1216 A, %	10(13)	30(24)	14(19)	– –

The pulses recorded from counters, were registered by a two-channel logarithmic counting rate measurer, of which the output characteristic was linear in the 2 – 2000 pulse/sec interval. The photon counter's nonlinearity, begininning from counting rates ∿ 1000 pulses/sec leads to the fact that the total counting characteristic of the device also becomes nonlinear for counting rates exceeding 10^3 pulses/sec; however, measurements can be conducted through 10^4 pulses/sec (see Fig.1). Incidently, such high counting rates were observed only near Earth during the first 10 minutes of flight.

The effectiveness of the counters was determined by Tiyt and Sheffer [3] by means of the vacuum monochromator of the Tartusk Astronomical Observatory add by way of connection to a standard photomultiplier, whose cathode was provided with a layer of sodium salicylate. Photomultiplier's comparison was conducted with the aid of a thermocouple along the Hg line λ 2537 A. It was assumed at the same time that sodium salicylate's quantum yield remains constant in the wavelength region from L_α to the Hg line. This method is described at further length in [3].

Assuming that the measurement errors have a casual character, the data on quantum yield of the three counters were corrected by measurements in interplanetary space, where the ratio of devices' readings must exactly equal the ratio of counter effectiveness in the λ1216 A. It is only necessary to take into account the contribution to devices' readings linked with cosmic rays. The latter quantity has been determined according to measurements on AIS Venera-3, where the second channel was not responding to the emission in L_α. The counting rate in this channel was equal to ∿ 30 pulses/sec over the extent of the entire flight, which is about 15 percent of the signal linked with the emission in the line L_α.

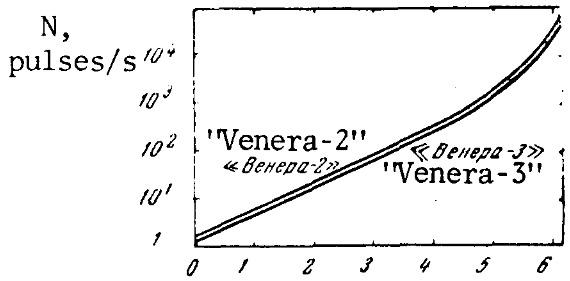

Fig.1. Device's output voltage as a function of counting rate of incoming pulses

The efficiency directly obtained by laboratory measurements is shown in Table 1 in parentheses. As an average, the departure of the measured value from the mean value does not exceed 25 percent which is quite satisfactory. The analysis conducted shows that the error in the absolute calibration taking into account the uncertainty of the calibration of the thermocouple does not exceed 30 to 50 percent either.

Both counters were mounted in a single block installed on the shady side of the AIS (Fig.2). In an operating regime whereby battery panels are oriented at the Sun, and such a regime was materialized in overwhelming number of cases, the angle between the optical axis of the photometer and the direction at the Sun was 107°. The photometer's visual ray with a field equal to 7° then described a cone with an aperture angle of about 140° and its axis directed at the Sun. In isolated cases, when the device was switched on during radiocommunication sessions with the AIS and the and the sharply-directed antenna was oriented toward the Earth, the angle between the photometer axis and the direction at the Sun differed little from 90°. During the ground session with Venera-2 the photometer field of vision parctically crossed the center of the Earth as it rotated around the axis directed at the Sun, which is clearly seen in Fig.3. The period of station's complete revolution was about 10 min, and during that time the device was interrogated 10 times. Such a regular rotation with constant angular velocity was imparted to the AIS beginning from about the distance of 12 R_E (R_E being the radius of the Earth). Prior to that the station performed a very slow rotation around the same axis with angular velocity tens of times lower than in the regular rotation regime. The minimum readings of the device correspond to the direction of the axis of the photometer, constituting an angle of ∿ 140° with the direction toward the center of the Earth. Shown in Fig.4b is the level of counter's minimum signal, the counter being sensitive to emission in the line L_α as a function of the distance from the center of the Earth..During measurements the angle "Sun - AIS - Earth" varies insignificantly, except during the first hour of flight. The character of variations is understandable from Fig.3, and its average value was ∿ 100°. Continuous measurements aboard AIS Venera-2 lasted through 20 Earth's radii.

During the near-ground session AIS Venera-3 practically did not spin around the axis directed at the Sun. The value of the operating counter's signal is shown in Fig.4,a. The readings of the second counter, registering the background of charged particles, are shown in Fig.5. However, because of the proximity of trajectories of both AIS, the results of these measurements may be also utilized for AIS Venera-2.

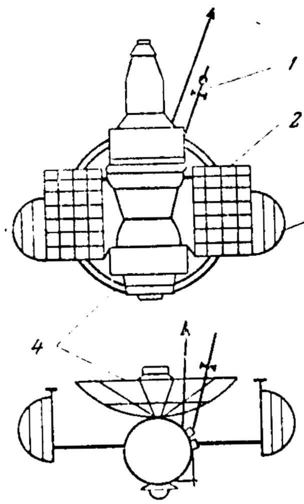

Fig.2. Disposition of the device on AIS Venera-2 and -3

1. magnetometer sensor; 2) solar battery panels; 3) thermoregulation system's radiators; 4) antenna. The arrows indicates the direction of photometer's optical axis

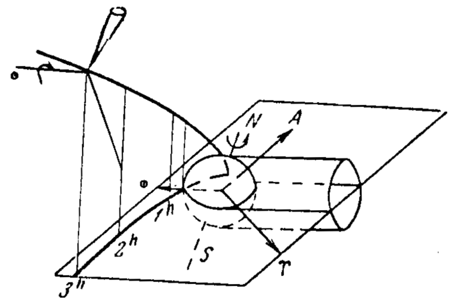

Fig.3. AIS's trajectory near the Earth. Shown here is the cone decribed by photometer's optical axis. The positions of the AIS 1, 2 and 3 hours after the beginning of flight is shown on trajectory projection on the ecliptic plane. The arrow A indicates the direction of annual rotation of the Earth

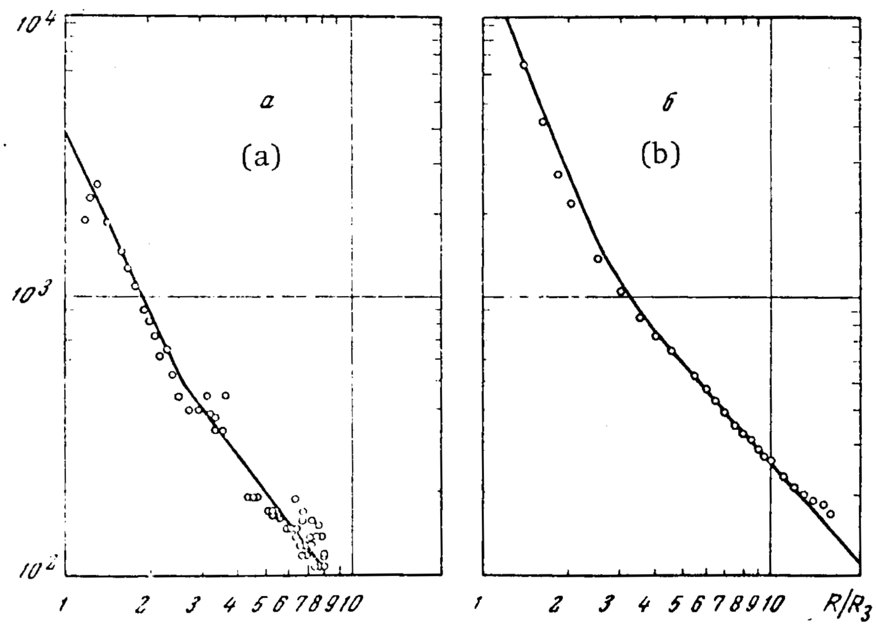

Fig.4. Counting rate of L_α-quanta as a function of the distance from the center of the Earth according to data of VENERA-3 (a) and counter's minimum signal according to data of VENERA-2 (b)

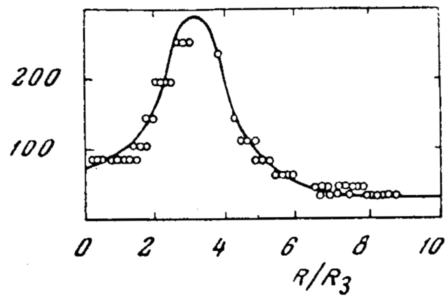

Fig.5. Counting rate of the background of charged particles according to data of the counter with filter made of calcium fluoride as a function of distance from the center of the Earth after Venera-3

In order to compute the concentration of neutral hydrogen n(R) by the observed emission flux I(R) in the line L_α, we shall make use of the evident relation

$$I(R_0) = \frac{1}{4\pi}\int_{R_0}^{\infty} n(R)\sigma_0(\pi F_S)\left(\frac{2\Delta\lambda_D}{\Delta\lambda_S}\right) dS, \qquad (1)$$

where σ_0 is the effective cross-section of resonance scattering at the center of the line, equal to $2 \cdot 10^{-13}$ cm^2; $\pi F_S = 2 \cdot 10^{11}$ quanta/sec is the flux of L_α-emission from the Sun beyond the Earth's atmosphere boundary; $\Delta\lambda_D$ is the Doppler half-width of the line of scattered radiation; $\Delta\lambda_S$ is the total width of solar emission line L_α, $2\Delta\lambda_D/\Delta\lambda_S = 3 \cdot 10^{-2}$; R_0 is the distance from the AIS to the center of the Earth.

It is necessary to perform the integration along the visual ray s at an angle (180° − ϕ) to the direction AIS – center of the Earth. In this case the element of integration path is

$$ds = \frac{RdR}{\sqrt{R^2 - R_0^2 \sin^2\varphi}}. \qquad (2)$$

Approximating $n(R) = n_0 / R^m$ and substituting n(R) and ds into (1), we shall have for $I(R_0)$ as a function of m the expressions

$$I(R_0) = F_0 \frac{1}{R_0}\left(\frac{\varphi}{\sin\varphi}\right) \quad \text{for} \quad m = 2, \qquad (3,a)$$

$$I(R_0) = F_0 \frac{1}{2R_0^2\cos^2\frac{\varphi}{2}} \quad \text{for} \quad m = 3, \qquad (3,b)$$

$$I(R_0) = F_0 \frac{1}{2R_0^3\sin^2\varphi}\left(\frac{\varphi}{\sin\varphi} - \cos\varphi\right) \quad \text{for} \quad m = 4, \qquad (3,c)$$

where

$$F_0 = \frac{1}{4\pi} n_0\sigma_0(\pi F_S)\left(\frac{2\Delta\lambda_D}{\Delta\lambda_S}\right). \qquad (4,d)$$

For the ratio $I(R,\phi = 40°)/ I(R, \phi = 0°)$ we shall obtain respectively for m = 2, 3 and 4 the quantities 1.10, 1.14 and 1.64. Therefore, assuming at computations $\Phi = 0$, and then introducing the correction according to (3), we should be introducing an error hardly exceeding 25 percent.

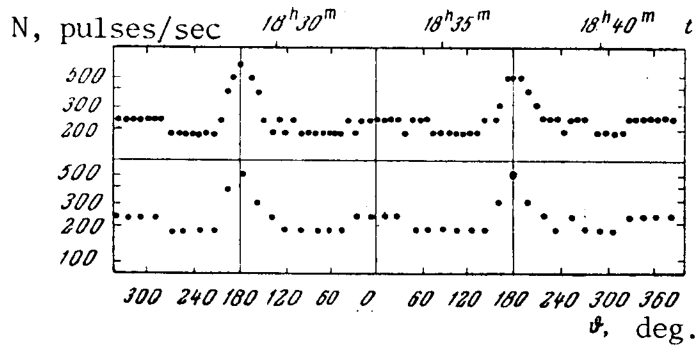

Fig.6. Two scannings passing through the Earth obtained from a distance of 26 R_E on 12 November 1965 on VENERA-2 as a function of AIS's rotation angle about the axis directed at the Sun

The origin of angles' count is arbitrary

For I(R) it is better to utilize a binomial formula of the form

$$I(R) = (A / R^{m_1}) + (B / R^{m_2}),$$

where A, B, m_1 and m_2 are assorted empirically, and then to find from formula (1) the expression for n(R). For the near-ground session obtained from VENERA-2 the following expression was found for n(R):

$$n(R) = 5{,}9\cdot 10^2 \left(\frac{16}{R^{4,9}} + \frac{1}{R^{2,1}}\right) cm^{-3}, \qquad (4,a)$$

valid straight through 20 R_E.

The analogous formula according to measurement data from AIS VENERA-3 has the form

$$n(R) = 8\cdot 10^2 \left(\frac{26}{R^{5,3}} + \frac{1{,}3}{R^{2,3}}\right) cm^{-3}. \qquad (4,b)$$

Since measurements on VENERA-3 lasted to 8 R_E, the further extension of the curve for n(R) according to formula (4,a) is not valid for R > 8R_E. Table 2 shows the density computed according to (4) and also by measurement data from AIS "ZOND-1".

During Venera-2 rotation at the distance of 164,000 km from the center of the Earth, the latter hit the visual field of the photometer (the angular dimension of the Earth's disk being 4°20' from that distance, which is less than the visual field of the device). Two scannings practically passing at the center of the Earth are illustrated in Fig.6 as a function of the rotation angle relative to the axis AIS – Sun. The readings of both counters are practically identical. Two circumstances call attention, namely, the presence of a plane maximum near the angles ±60°, exceeding the background level of L_α-radiation by 30 percent and the asymmetry of the profile during scanning of the geocorona. The secondary maximum has a ∿ 90° dimension in the celestial sphere, and its center is located at a distance of approximately 180° from the direction at the center of the Earth, which corresponds to the following coordinates on the celestial sphere: $\alpha = 22^h; \delta = +32°$. This position corresponds in Fig.3 to about the direction of photometer's axis directed upward, i. e. at an angle of ∿ 15° from the pole of ecliptic. If we assume that there is hydrogen concentration in the given direction, its average density may be easily computed by formula (1). Postulating arbitrarily the region's dimension as being ∿ 300,000 km, which corresponds to the doubled distance from the AIS to the Earth, we shall find that the mean density of hydrogen atoms in the cluster is ∿ 0.5 atom/cm^3. However, a direction at emission maximum, not coinciding with either the ecliptic plane or antisolar direction is difficult to explain. The latter compels us to deny ourselves the attempt to ascribe the observed phenomenon to the gas "tail" of the Earth.

TABLE 2

Density of neutral hydrogen, cm^{-3}

R/R_E	R 10^3, km	after Venera-2	after Venera3	after Zond-1
1,50	9,6	$1,6\cdot10^3$	$2,8\cdot10^3$	—
2,00	12,8	$4,6\cdot10^2$	$7,6\cdot10^2$	$1,9\cdot10^2$
2,50	16,0	$2,0\cdot10^2$	$2,8\cdot10^2$	$1,2\cdot10^2$
3,00	19,0	$1,1\cdot10^2$	$1,5\cdot10^2$	$8,4\cdot10$
3,50	22,4	$6,9\cdot10$	$1,0\cdot10^2$	$6,5\cdot10$
4,00	25,6	$4,7\cdot10$	$5,6\cdot10$	$5,1\cdot10$
4,50	28,8	$3,5\cdot10$	$3,9\cdot10$	$4,2\cdot10$
5,00	32,0	$2,7\cdot10$	$2,8\cdot10$	$3,6\cdot10$
7,50	47,7	$1,1\cdot10$	$1,0\cdot10$	—
10,00	63,5	5,9	—	—
15,00	95,2	2,6	—	—
20,00	127	1,5	—	—

The asymmetry of the main maximum linked with the passage of the visual field through the center of the Earth may be explained only in the assumption of geocorona nonsphericity.

It is also possible to compute by the data on geocorona scanning the distribution of atomic hydrogen in the neighborhood of the Earth analogously to the way the electron density is determined in the solar corona. The problem is reduced to the solution of the Abel integral equation

$$I(\rho) = \int_{-\infty}^{+\infty} F(R)\,dy, \tag{5}$$

where $I(\rho)$ is the surface brightness of the geocorona as a function of the visible distance ρ; $F(R)$ is the volume radiance (luminosity), determined by correlation (3,d). Integration is performed along the visual ray $\underline{y}$. However, the accuracy of the thus obtained data will not be great, which is linked with the poor knowledge of device's orientation during the passage of the field of vision near the Earth. The deviation by about 5° lowers the computed density by about 30 times. Besides, the dimension of the field of vision is almost twice the visible diameter of the Earth, and this strongly underrates the results. The computations conducted have shown that the density is approximated by the expression

$$n(R) = \frac{1{,}2 \cdot 10^2}{R^{1{,}6}} \text{ см}^{-3}, \tag{6}$$

where $R > 2.5\ R_E$, which is about 3 to 4 times less than the value determined from formula (4,a).

It should be noted that the secondary maximum, approximately located at angle of 180° to the direction at the Earth, is situated near the Milky Way in the Lacerta Lac constellation, whereupon its maximum is displaced from the center of the Milky Way band by about 15°. The asymmetry near the Earth is also possibly linked with the passage of photometer's field of vision through the Milky Way near the Canis Major constellation ($\alpha = 7^h$, $\delta = 20°$). Apparently Sirius also hit the field of vision.

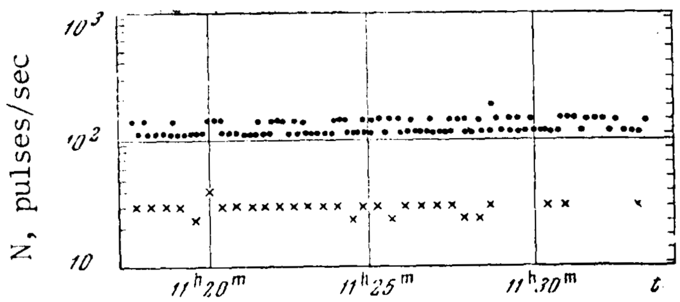

Fig.7. Readings of the device in one of the communication sessions on 29 Nov.1965 with AIS VENERA-3.

Dots) channel sensitive to L_α-emission; crosses) background in the 1225 - 1340 A band correeponding to cosmic ray level. Discrete level of the system of data (*)

Quite similar a picture was observed also in other communication sessions as AIS Venera-2 rotated, with two extended maxima of about 100° each. The emission intensity in the band λλ 1050 – 1340 A was $\sim 2.5 \cdot 10^{-5}$erg/cm^2· ·sec·sterad, or 25 R. The question of L_α-emission from Milky Way is consi= dered in detail in the works [4, 5].

Besides the continuous registration of scattered UV radiation near the Earth (to 20 R_E on Venera-2 and to 8R_E on Venera-3, the registration of devices' readings was periodically conducted during communication sessions for 5 to 15 min. and also every 4 hours in the course of the entire flight time.

In the latter case one channel of the device was interrogated twice with a 30 seconds interval, and the other once. An example of a session of 15 min. duration was shown in Fig.6, shortly after the end of the near-ground portion of the flight of Venera-2. During that time the station completed two complete revolutions around an axis directed at the Sun. Shown in Fig.7 is radiocommunication session with AIS Venera-3 on 29 December 1965 of about the same duration. The scattering of the points corresponds well to the dispersion of the measured counting rate of the number of photons

$$\sigma_V \sim 1/\sqrt[4]{N}, \qquad (7)$$

where σ_V is the dispersion of device's output voltage, N is the counting rate in pulses/sec.

The character of the dependence of (7) on N is determined by the fact that the time constant of the logarithmic intensity-meter is inversely proportional to the square root of the value of the counting rate.

The main singularity, noticeable outright from all the indicators in the communication sessions on both AIS, consists in the absence of concentration of the observed emission toward the ecliptic plane. The second session, conducted from the AIS Venera-2 from a distance of ~ 700,000 km, had shown a pattern corresponding to Fig.7.

The mean value of brightness in the channel sensitive to L_α-emission corresponds to $7 \cdot 10^{-5}$ erg/cm ·sec·sterad, which is in good agreement with the measurements on the station "ZOND-1" ($1.5 \cdot 10^{-4}$ erg/cm^2·sec·sterad

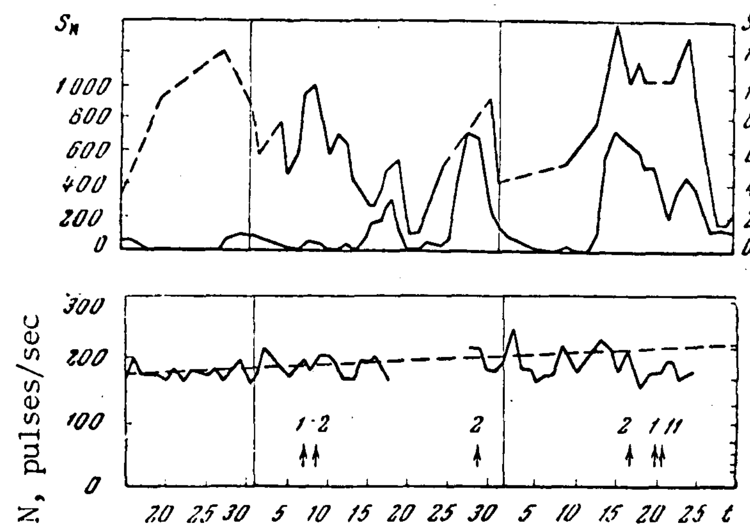

Fig.8. Intensity of L_α-emission (taking into account the cosmic ray background) averaged for a day from data of Venera-2 (below); the area of calcium flocculi expressed in units 10^{-3} of hemisphere area of the solar disk (above, upper curve, right-hand scale) and the aggregate area of sunspots in units 10^{-6} of Sun's hemisphere (above, lower curve, left-hand scale)

Continuous measurements during nearly three months have shown that the indicated value remains constant with a precision to ∿ 20%. Mean daily data on measurements from Venera-2 are shown in Fig.8. In order to obtain this quantity averaging of measurements was performed in sessions, whereupon each measurement was found as the average of three readings (two in one channel and one in the other). Therefore, the mean value for a day was found as the mean arithmetic value of 18 separate readings. The precision formally found for such averaged readings is about 25 percent; however, averaging of measurements completed with the aid of a discrete system of data transmission may induce objections. In our viewpoint such processing method allows us to establish the presence of systematic variations with a period of 2 to 3 days, and also a monotonic variation of the level of L_α-emission in a period of three months. Presented in the lower part of Fig.8 is the result of analysis by the method described. Isolated readings in communication sessions, similar to those shown in Fig.7, fit very well the curve. It may be assumed that the fluctuations having a period of ∿ 5 days are real and have no connection with causes due to the apparatus. Apparently the emission observed is linked with the hot interplanetary hydrogen, whose concentration may precisely be obtained from our measurements analogously to computations of [6]

$$I=\frac{1}{4\pi}n\sigma_0\left(\frac{2\Delta\lambda_D}{\Delta\lambda_S}\right)\int_{R_0}^{R_1}\frac{S_0}{R^2}\,dR, \qquad (8,a)$$

where $4\pi S_0$ is the total flux of L_α-emission from the Sun; R_1 is the external radius of a sphere filled by "hot" hydrogen atoms.

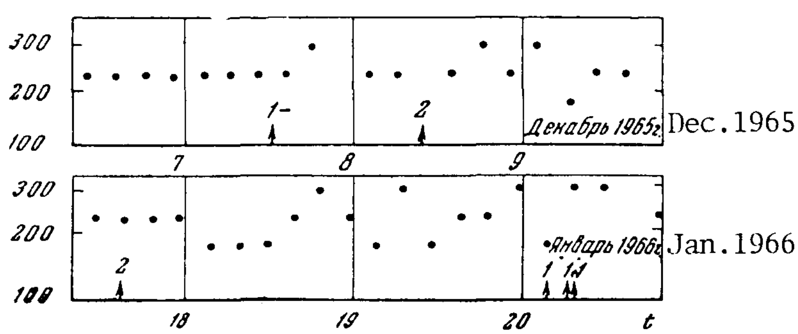

Fig.9. Readings of the device on Venera-2 for the 7-9 Dec.1965 and 17-20 Jan.1966

Chromospheric flares are indicated

It is evident that for R_1 several times greater than R_0, I is independent of R_1 and is equal to

$$I(R_0)=\frac{S_0}{4\pi}n\sigma_0\left(\frac{2\Delta\lambda_D}{\Delta\lambda_S}\right)\frac{1}{R_0}. \qquad (8,b)$$

Equating (8,b) with the found value of $7 \cdot 10^{-5}$ erg/cm$^2 \cdot$ sec$\cdot$sterad, we shall find that the mean concentration is $n = 3 \cdot 10^{-3}$ cm^{-3} for any temperature of hydrogen atoms, for the product $\sigma_0 (2\Delta\lambda_D \ / \ \Delta\lambda_S)$ does not depend on the admitted temperature. Expression (8,b) depends little on R, which decreased as the AIS drifted toward the Sun. A curve proportional to the quantity 1/R is drawn by dashes inn Fig.8. However, the feeble dependence of the measured brightness on distance does not provide the possibility to judge on the fulfillment of this law. Yet, however, the general character of intensity variation for three months speaks in favor of the assumption made.

The upper part of Fig.8 shows the data characterizing the solar activity during the flight period of AIS: the aggregate area of calcium flocculi and the aggregate area of sunspots. There is no correlation of any kind with the intensity of scattered $L\alpha$-radiation. The chromospheric flares observed are marked by arrows in the same figure. No notable increase in L_α-intensity was then observed either. The same data without averaging for a day are plotted in the same Fig.8 with four-hour interval for 7, 8, 9 December 1965 and 18, 19, 20 January 1966, when 6 chromospheric flares were observed. No increase in L_α-intensity was observed here either.

Our observations are in full accord with the available representations on the character of events during chromospheric flares [7], when a sharp increase of X-ray emission, of emission in the line λ 304 A, and also of lines of elements with a sufficiently high ionization potential (upper chromosphere and transitional layer) [8]. At the same time L_α-emission remains constant with a precision of 10 to 20 percent. The scattered radiation in interplanetary medium must be endowed with still greater stability. Direct measurements of solar L_α-emission [9] show about the same character of variations. The constancy of scattered L_α-emission is evidence of stability of the "pumping" mechanism of neutral hydrogen into the interplanetary medium. Incidently, such a situation may be characteristic only for the minimum epoch of solar activity. Very powerful solar corpuscular eruptions from the Sun are indispensable for a substantial variation in the quantity of "hot" hydrogen atoms in a "reservoir" with radius of some 10 a.u., whereupon the time of filling such a volume will be of $\sim 3 \cdot 10^5$ sec, which may lead to notable effects.

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WX SWEET
RR KURZWEG
RTR NEILL
VOLT D.C.

OTHER CENTERS

A M E S R C

SONETT
LIBRARY

LANGLEY R C

116 KATZOFF
160 ADAMSON
235 SEATON
185 WEATHERWAX

J. P. L.

75 NEWLAN

M. S. C.

TA HESS
TG MODISSETTE
TG4 ROBBINS

N. R. L.

FRIEDMAN

U.C.BERKELEY

FIELD
WILCOX

SWCAS

JOHNSON