NASA TECHNICAL MEMORANDUM NASA TM-75639

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(NASA-TM-75639) ELECTRICAL DISCHARGES IN THE ATMOSPHERE OF VENUS (National Aeronautics and Space Administration) 18 p HC A02/MF A01 CSCL 03B

N79-25961

Unclas

G3/91 22268

Translation of "Elektricheskiye Razryady v Atmosfere Venere", Academy of Sciences USSSR, Institute of Space Research, Moscow, Report, 1979, pp 1-16

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546 JUNE 1979

ELECTRICAL DISCHARGES IN THE ATMOSPHERE OF VENUS

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Analysis of some results, obtained in an experiment involving the study of the electrical activity of Venus, gave the following information: electrical discharges occur in the cloud layer; their energy is roughly the same as in lightning on Earth, but the pulse repetition frequency of the discharges is much greater, reaching 30 sec^{-1}. /1*

One of the problems involved in the study of Venus is the origin of the minor components of its atmosphere, including the sulfur-containing components. The role of electrical storm discharges is well-known in the formation of such components of the Earth's atmosphere as nitric oxides, ozone, and others. It was also shown that, in the early stages of evolution of the Earth's atmosphere, the charges lead to the occurrence of primitive organic compounds. One can assume that the storm discharges may play an important role in the formation of the minor components of the atmosphere of Venus. The favorable conditions for the accumulation of charges create intense movement on the level of the cloud cover of Venus.

The purpose of one of the experiments on the "Venus" 11 and 12 vehicles, which received the name "Thunderstorm", was the investigation of the electrical activity of the planet's atmosphere (Ksanfomaliti *et al.*, 1979). During the period of preparation of the experiment, independent from our work, Khara (1976) came out with the idea of the probable electrical storm activity of Venus.

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*Numbers in the margin indicate pagination in the foreign text.

The "Thunderstorm" instrument was a miniature super-long spectrum analyzer of the 8-100 kHz range, with a high threshhold sensitivity, equipped with an external loop antenna. There were 4 frequency channels: 10, 18, 36, and 80 kHz, with band widths of 1.6, 2.6, 4.6, and 14.6 kHz, respectively. The spectrum analyzer was equipped with two integral discriminators, with 64 and 256-unit counters, a device for automatic regulation of amplification, and built-in calibration. We would note that any initial data were absent during preparation of the experiment. The instrument was switched on at an altitude of ~60 km, and operated during re-entry and on the surface of the planet after landing. /2

Radio noises were recorded which were quite similar to terrestial atmospheric radio noises, occurring during electrical storm discharges. Comparison of the development of the surges of radio noises during re-entry of the two vehicles along identical courses, in one and the same region of the planet, is carried out on a fragment of a telemetric recording in figure 1. The graphs were constructed as a function of the Moscow time of receiving of the information on Earth. Plotted along the vertical are the intensities of the field in each of the four frequency channels. Because of the compressed horizontal scale and the small time constant of the instrument (0.24 sec), the recorded discharges have the form of vertical lines. During the re-entry of "Venus-11", the electrical storm phenomena were quite intense, with frequent discharges, whereas during the re-entry of "Venus-12", the electrical storm situation was calmer. In order to avoid misunderstandings, we will note that, in speaking of a thunderstorm, we mean only electrical discharges in the atmosphere, similar to terrestrial lightning, and not the falling of any precipitation. The development of a large surge, consisting of thousands of individual discharges, is clearly evident in figure 1. The telemetric recordings contain a great number of similar phenomena. Of particular interest is the group of surges which switched from frequency channels of 80 and 36 kHz to channels of 18 and 10 kHz, with a delay of several minutes. Under conditions of the extremely weak dipole magnetic field /3 of Venus, such a delay requires special explanation. The intensity of the electromagnetic field of the radio noises, at altitudes of less than 3 km and on the surface, was, with one exception, very small, which can be explained by radio refraction in the dense atmosphere of Venus. The first to indicate this was V. V. Andreyanov, to whom the authors express their gratitude for the useful discussion.

On the whole, the interferences, associated with the electrification of the vehicles during their movement, were insignificant, which is corroborated both by the dissimilarity of the phenomena during the re-entry of the two vehicles, and by many characteristics of the telemetric recordings, one of which we will now turn our attention to.

Preliminary Analysis of Surges of Radio Noises

Processing of the results of the experiment has still not been completed; therefore, the materials given in the article should be viewed as preliminary.

We will dwell here on one of the unexpected, but quite interesting, results of the experiment. Picked out among the numerous groups of surges, recorded by "Venus-11", is a series distinguished by a periodicity which is noticeable even by eye (fig. 2). This group was recorded from 6 hours 04 minutes to 6 hours 11 minutes. It consists of six large surges, following with increasing amplitude. In each packet there are several hundred impulses, which correspond to individual discharges. The first two surges are divided by intervals of about 90 and 80 sec, and the subsequent ones — by 50

sec each. The entire sequence ends with the abrupt disappearance of the signal after 6 hours 11 minutes. This portion of the experiment proved especially productive. As is shown below, the successful combination of the altitude of the vehicle and the position of the source made it possible to find the most important parameters of the Venutian thunderstorm with a minimum of assumptions. The altitudes which the /4
vehicle passed through during this time were from 17 to 13 km.

L. V. Ksanfomaliti proposed that the origin of this sequence is associated with the slow rotation of the vehicle during re-entry, which is explained by aerodynamic reasons. Comparison of the periodicity of the surges with the measured angular velocity of rotation of the vehicle ω_x around its vertical axis supported the correctness of this assumption: ω_x varied within the range of from 2 to 7 degrees/sec, which gives a semiperiod of rotation of from 90 to 26 sec, with an average value of 58 sec. The characteristic of directivity of the loop antenna, utilized in the instrument, is described by the following function:

$$F(\theta) = \sin\theta, \qquad (1)$$

where θ is the angle between the perpendicular to the plane of the loop and the direction towards the signal source. If the antenna is located in the vertical plane, and the azimuth angle of the source is α, then the tension at the output of the loop antenna, with an effective altitude H and a field intensity E, is

$$U = EH\sin(\omega_x t + \alpha). \qquad (2)$$

Thus, the rotation of the vehicle should lead to a 100% modulation of the signal picked up from a point source, located at roughly the same altitude as the receiver.

The actual position is, of course, more complex. First and foremost, the antenna is located so that the loop forms a 45° angle with the horizontal plane of the vehicle. Then, it is difficult to imagine a powerful source of radio noises, which possesses such small dimensions that it can be considered a point source. All the same, such an assumption was also put forth: it is common knowledge that, with strong eruptions of volcanoes on Earth, numerous lightning discharges are observed above them. But, insofar as nothing is known, as yet, about volcanic activity on Venus, we will attempt to explain the observed phenomenon from the point of view of electrical storm activity in the atmosphere of Venus. /5

First and foremost, we will determine the angular dimensions of the source. Analysis of telemetric information shows that, in the intervals between surges, the field intensity is not equal to zero (fig. 3). Of course, this may be a background from other sources; however, in the period from 6 hours 04 minutes to 6 hours 12 minutes, at the edges of the described group of surges, the background was very low. Study of the recordings, similar to figure 3, shows that, at frequencies of 10 and 18 kHz, the minimum level of radio noises U_{min} between the surges was 5-8 $\mu V/m^{-1} Hz^{-1/2}$. Taking into account the symmetrical, two-loop form of the characteristic of directivity of the antenna, we have, approximately, the angle at which one-half of the source is observed

$$\delta = \arcsin \frac{U_{min}}{2 U_{mx}}, \qquad (3)$$

which gives $\delta = 1.4-3.8^{\circ}$, or an average of 2.6°.

<u>Distance to the Source of the Surges</u>

The next step is an attempt to determine the distance to the source of the surges. The "ionosphere-surface" wave-guide plays an important role in the propagation of super-long waves in the Earth's atmosphere. The presence of a sufficiently dense ionosphere on the daylight side of Venus, it would seem, should also lead to further propagation of radio waves of the super-long range. In addition, both vehicles noted a profound drop in the intensity of the electromagnetic field at the surface of the planet, which may be attributed to some mechanism of absorption of radio waves. Proceeding from here, we will then examine only the forward-travelling wave, when the major role in receiving of the radiation is played by the altitude of the emitter above the surface and the strong refraction in the dense atmosphere. The greatest altitude at which discharges may occur is no higher than the lower boundary of the ionosphere, which is located at a level of 80-90 km, based on the data of radio-refraction experiments on space vehicles. However, it is more likely that the source of radio noises—lightning—is located in the cloud layer, the upper boundary of which, according to Ksanfomaliti (1977), corresponds to a level of 71 km. /6

Then, insofar as both the source and the vehicle are located in the atmosphere, a forward-travelling wave, which is not weakened by the surface, is propagated between them. In this case, the intensity of the field E from a discharge with an energy W, originating within a sufficiently small time τ, can be computed approximately according to the theory (see, for example, Feinberg, 1961) in the following manner:

$$E \propto \frac{\sqrt{W/\tau}}{R} \sin\vartheta, \qquad (4)$$

where R is the distance between the source and the receiver, and θ is the angle between the lines of the dipole of the source and the direction to the receiver.

We will examine the possible positions of the source of the surges. In the first variation, the source may be located nearby—in accordance with the position of the antenna, in the plane passing through the vehicle and inclined to the horizon at a 45° angle. Three cases are possible: the source is located in the cloud cover, then the distance to it is $R_1=\sqrt{2}(70-15)=78$ km; on the surface, then $R_2=\sqrt{2}\cdot 15=21$ km; or, it is located at intermediate altitudes. (We would recall that 15 km is the average altitude of the vehicle during recording of the signals from this source of surges). The second variation will be characterized by the distant position of the source (on the radio horizon). Serving as the criterion for the choice between these variations is the comparison of the energy in a single discharge with the data known from analysis of terrestial thunderstorms. We will take the energy of terrestial lightning as equal to $W_o=10^8$ Joules, which corresponds to a potential difference of $75\cdot 10^6$ volts, and a transferable charge of 1.3 Coulombs. /7
We will also think that τ is constant (for terrestrial thunderstorms, it is about 100 microseconds).

The spectral intensity of the field from lightning discharges in the Earth's atmosphere is complex when expressed analytically. Often utilized is an averaged model of the lightning, which reflects the average figures of the spectral density of its radiation—Yuman (1972), Fizich. ents. slovar' (1960). Such a model is given in table 1, which also includes the results of measurements for the examined case.

The magnitudes of the energy in the discharge, which provide the intensities given in table 1, are found from (4) as

TABLE 1

a. Частота, кГц	10	18	36	80
b. Напряженность поля E_0 на стандартном расстоянии от источника R_0 = 10 км мкВ/м $Гц^{1/2}$ (Земля)	$20 \cdot 10^3$	$11 \cdot 10^3$	$5,6 \cdot 10^3$	$2,5 \cdot 10^3$
c. Измеренная напряженность $E_{изм}$, мкВ/ м $Гц^{1/2}$ (Венера)	110	60	33	12

Key: a. Frequency, kHz
b. Intensity of field E_o at a standard distance from the source R_o=10 km, $\mu V/m\ Hz^{1/2}$ (Earth)
c. Measured intensity E_{meas}, $\mu V/m\ Hz^{1/2}$ (Venus)

$$W_{1,2} = W_0 \left(\frac{E_{изм} R_{1,2}}{E_0 R_0} \right)^2 \qquad (5)$$

and are given in table 2.

TABLE 2

a. Частота, кГц	10	18	36	80
W_1/W_0	$1,8 \cdot 10^{-3}$	$1,8 \cdot 10^{-3}$	$2,1 \cdot 10^{-3}$	$1,4 \cdot 10^{-3}$
W_2/W_0	$1,3 \cdot 10^{-4}$	$1,3 \cdot 10^{-4}$	$1,5 \cdot 10^{-4}$	10^{-4}

Key: a. Frequency, kHz

Such small energies in the discharge, thousandths or ten-thousandths of the energy of terrestrial lightning (Yuman, 1972, Imyanitov et al., 1971), are doubtful. The tension of the breakdown in carbon dioxide requires somewhat greater values than in air. As far as an aerosol medium is concerned, only the accumulation of charges in the clouds is determined, but not the mechanism of the discharge itself, which is identical both in air and in carbon dioxide. Therefore, it is logical to expect energies of the discharges on the same order as in terrestrial lightning. This is precisely the result provided by the second variation, when the source is located on the radio horizon. /8

We will turn once again to figures 2 and 3. The sequence of surges breaks off sharply at 6 hours 11 minutes. Such a nature of the changes in the signal can be explained most simply by the passage of the source beyond the radio horizon, whereas the increase in the amplitudes fully corresponds to the figure 1, examined above. To which distances does this variation correspond? We will make use of table 1 once again, and calculate the distances

$$R_3 = \frac{E_0 R_0}{E_{изм}} , \qquad (6)$$

proceeding from the constant energy in the discharge, equal to 10^8 Joules. The obtained distances are given in table 3.

TABLE 3

a. Частота, кГц	I0	I8	36	80	b. среднее
R_3, км	I820	I837	I687	2088	I858

Key: a. Frequency, kHz b. average

If the source is actually located so far away, then the disappearance of the signal at 6 hours 11 minutes is fully explained by the radio passage. But will such a source be located on the radio horizon? This would be a good corroboration of the found interpretation.

Distance of Radio Horizon /9

If the altitude of the vehicle h and the source of the signal z are equal to 15 and 70 km, respectively, then the distance to the radio horizon, with a planet radius **a**=6052 km, according to the formula for straight-line visibility (Chernyy, 1972), is equal to:

$$R = \sqrt{2a} \cdot (\sqrt{h} + \sqrt{z}) = 1347 \text{ km}. \qquad (7)$$

The magnitude of the angle of refraction was calculated, proceeding from the distribution of the density of the atmosphere of Venus at the altitude given by Kuz'min and Marov (1974). The method of calculation and the obtained results will be set forth in another article. Here, without conclusion, we will give the following result: if the vehicle is located at an altitude of 15 km, the greatest angle of refraction for a ray, reaching a level of 70 km, is 6°, which provides an increase in the distance by 320 km, for a radius of 6120 km. Thus, the total distance to the radio horizon is equal to 1650 km, which, within the limits of accuracy of our calculation, more than satisfactorily coincides with the average value in table 3. Thus, the source is actually beyond the radio horizon.

Thus, three circumstances affect the position of the source of the surges: the coincidence of the energy in the discharge with the known magnitude for terrestrial lightnings; the distance to the radio horizon which coincides with the calculated distance of the source; the total disappearance of the signal, which coincides to its radio passage.

The surges of radio noises, shown in figures 2 and 3, made it possible to find a number of other parameters of Venutian thunderstorms as well. The structure of the surges makes it possible to conclude that all of the impulses are attributed to a single source. Shown in figure 4 is the histogram of the speed of counting of the impulses. From this histogram, it follows that the average frequency of the discharges in a single source is very high, and reaches 20 pulses/sec, which greatly exceeds the analogous parameter of terrestrial thunderstorms. Other parts of the telemetric recording give even greater frequencies. /10

The distance and the angular dimensions of the source found above make it possible to determine its length: 150 km, which is a quite extensive storm front. Proceeding from the rate of re-entry of the vehicle and the time of radio passage, the vertical extent of the radiating medium is determined to be 1-2 km. Finally, figure 3 makes it possible to determine the statistical dispersion of energy in the discharges, assuming τ as a constant. The similarity of the amplitudes of the pulses indicates that all of the discharges probably occur in the cloud layer, between its individual parts.

Conclusion

1. First recorded in the experiment were the low-frequency electromagnetic radio waves of the atmosphere of Venus, associated with electrical discharges in the cloud layer, at altitudes of 50-70 km.

2. The energy in the discharges is quite close to the energy liberated during discharges of terrestrial lightning.

3. The extent of the electrical storm area is close to 150 km.

4. The average pulse repetition frequency of the discharges reaches 20 sec^{-1} and more, and greatly exceeds the frequency of discharges during terrestrial electrical storms.

5. In the period of investigations on "Venus-11" and "Venus-12", electrical storm phenomena on Venus had a local, non-global nature.

6. Proceeding from the great total number of discharges per unit of time in the atmosphere of Venus, and their considerable energy, it seems likely that the sometimes observed illumination of the nocturnal side of Venus is explained by the temporary increase in electrical storm activity.

REFERENCES

Chernyy, F. B., Rasprostraneniye radiovoln Propagation of Radio Waves , Sov. radio, Moscow, 1972.

Feinberg, Ye. L., Rasprostraneniye radiovoln vdol' zemnoy poverkhnosti Propagation of Radio Waves Along the Earth's Surface , Izd. AN SSSR, Moscow, 1961.

Fizicheskiy entsiklopedicheskiy slovar' Physical Encyclopedic Dictionary , Vol. 1, 100 (1960).

Hara, T., Lightning in the Planetary Atmospheres and in the Primordial Solar Nebula, Preprint of the University of Kyoto, Japan, 1976.

Imyanitov, I. M., Chubarina, Ye. V., Shvarts, Ya. M., Elektrichestvo oblakov Electricity of Clouds , Gidrometizdat, Leningrad, 1971.

Ksanfomaliti, L. V., Ganpantserova, O. F., Petrova, Ye. V., Suvorov, A. P., Pis'ma v AZh 5, 5 (1979).

Ksanfomaliti, L. V., Teplovaya asimmetriya Venery Thermal Asymmetry of Venus , Doctoral Dissertation, IKI AN SSSR, 1977.

Kuz'min, A. D., Marov, M. Ya., Fizika planety Venera The Physics of the Planet Venus , Nauka, Moscow, 1974.

Yuman, M., Molniya Lightning , Izd. Mir, Moscow, 1972.

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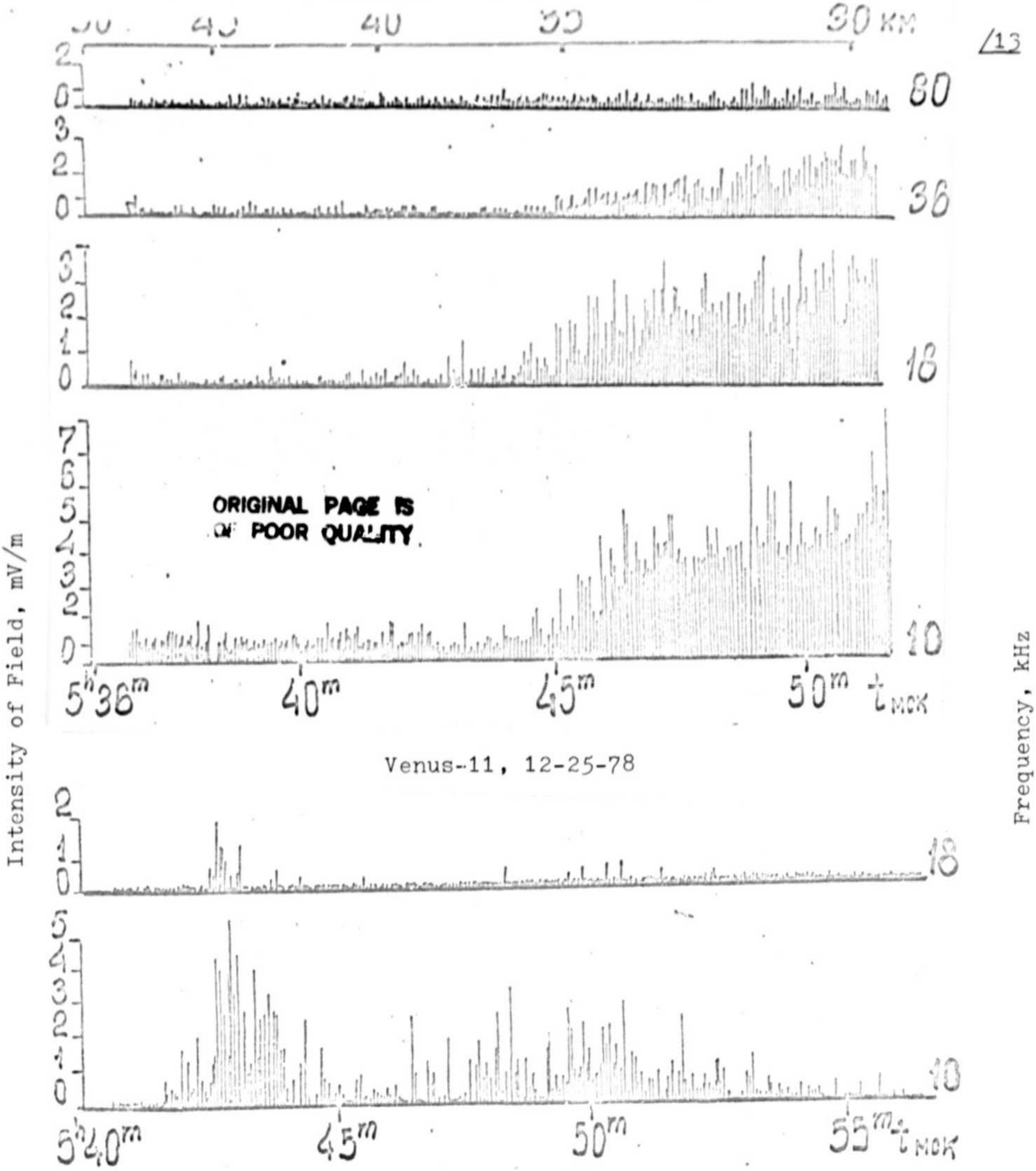

Venus-11, 12-25-78

Venus-12, 12-21-78

Fig. 1.

Comparison of the recorded electrical activity of the atmosphere of Venus during re-entry of the vehicles "Venus-12" (2 lower graphs) and "Venus-11" (4 upper). Altitude scale belongs to both vehicle. The signal was recorded in the 1.6, 2.6, 4.6, and 14.6 kHz bands at frequencies of 10, 18, 36, and 80 kHz, respectively.

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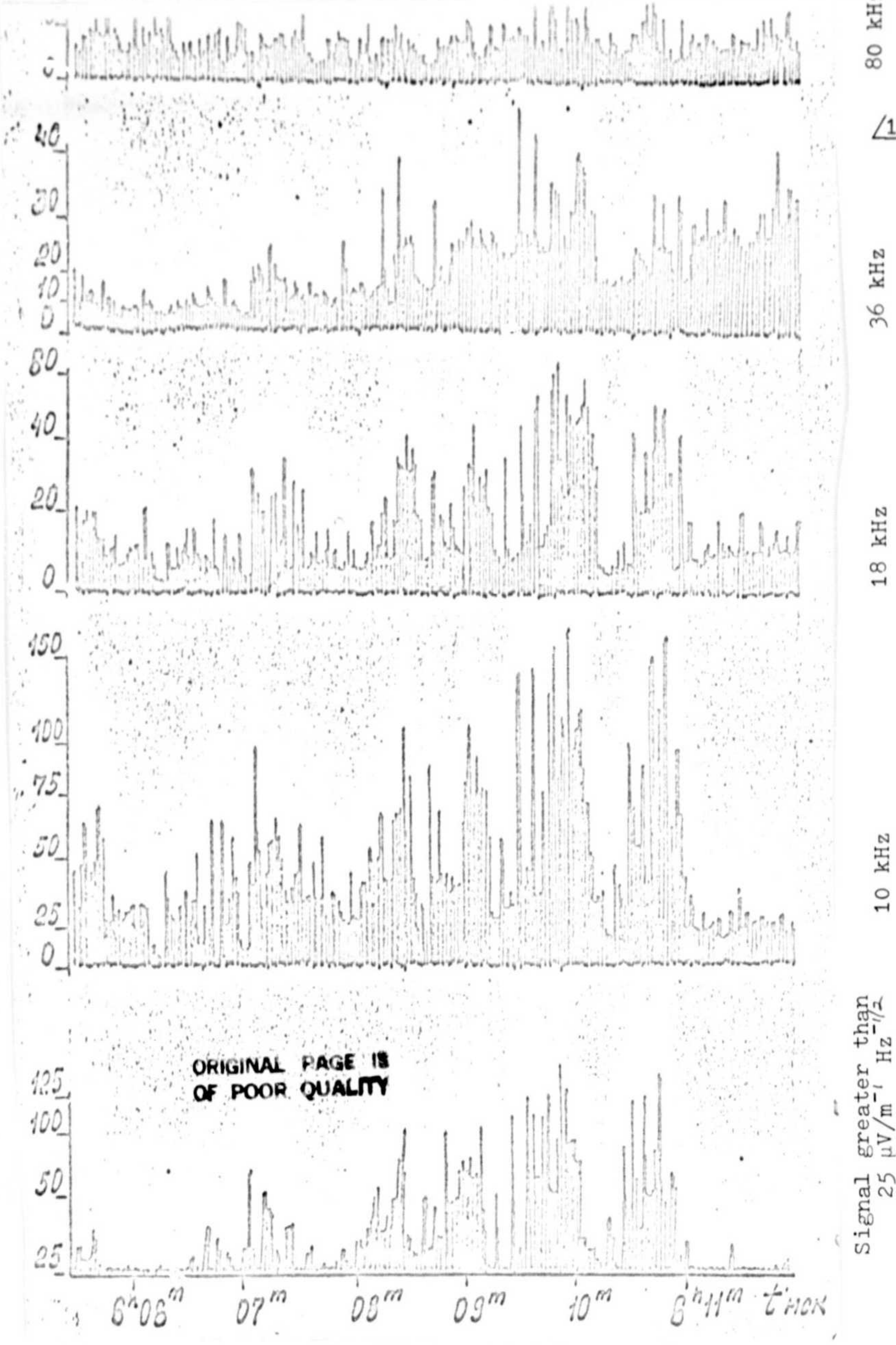
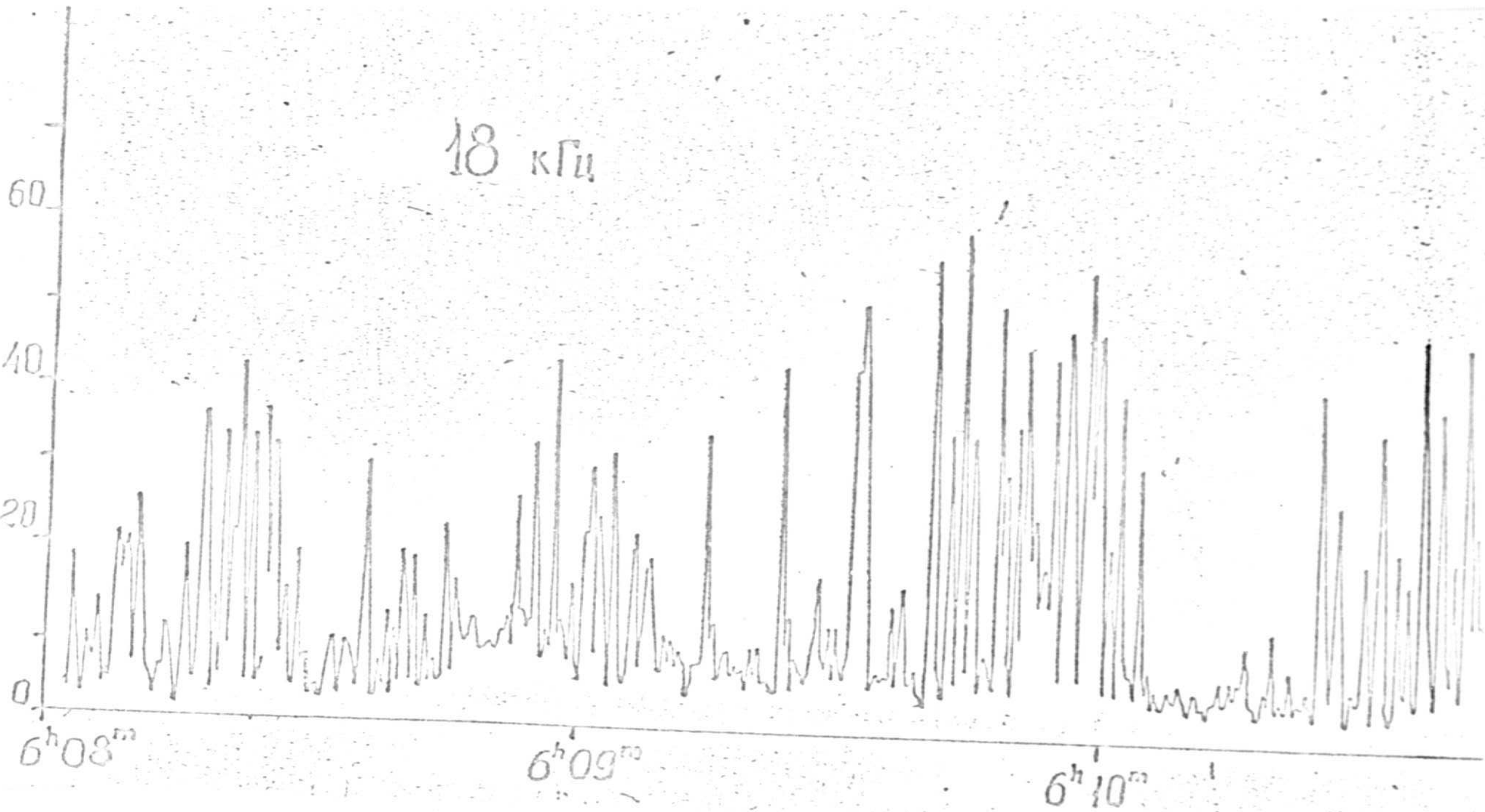


Time of terrestrial recording
Fig. 2. Periodic sequence of surges of radio noise, recorded by "Venus-11" at altitudes of 17-13 km.



Time of terrestrial recording, Moscow

Fig. 3. Same as in Fig. 2, for 18 kHz channel on an increased time scale.

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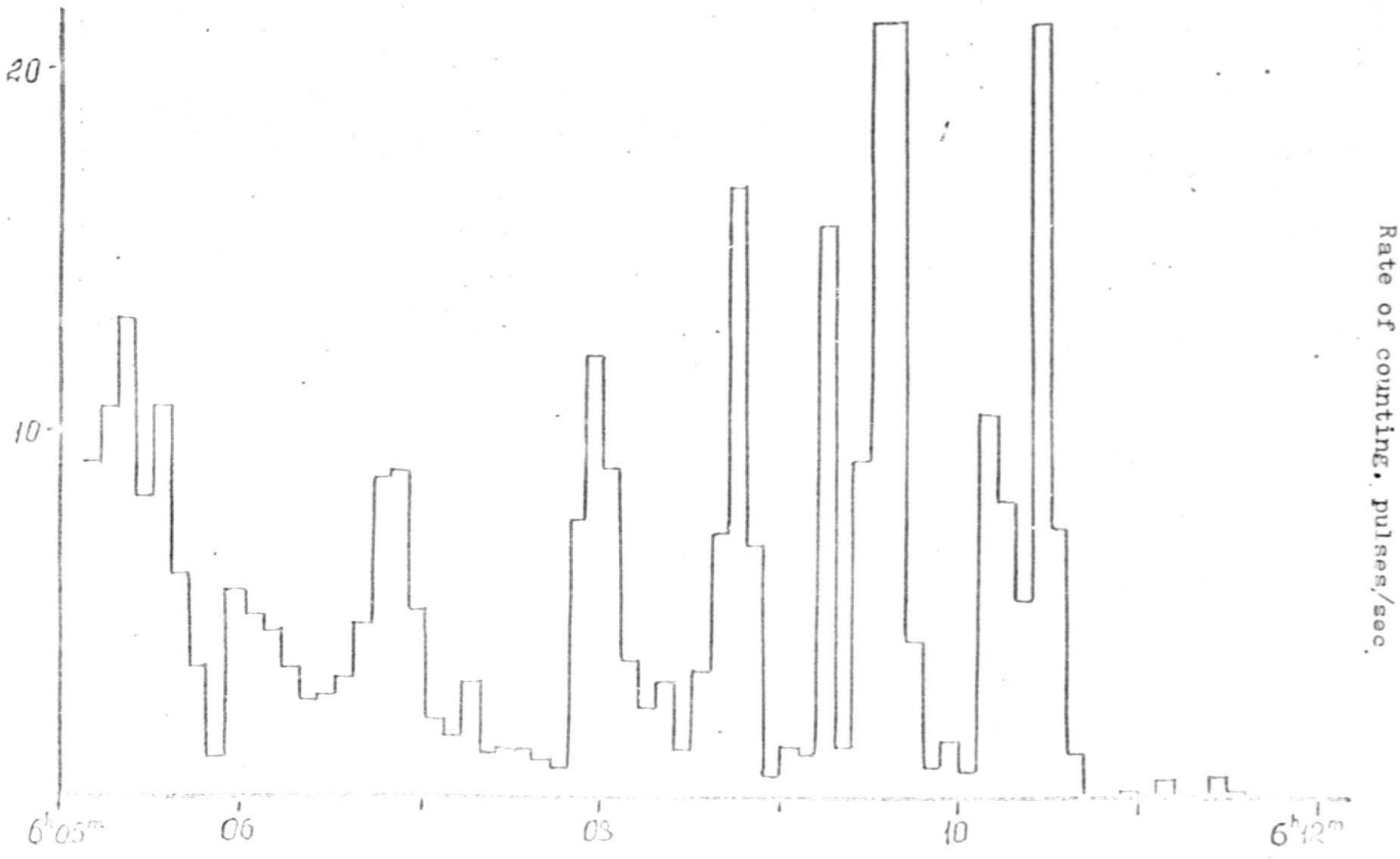

Fig. 4. Histogram of rate of counting of pulses in the channel of integral discriminator, corresponding to fig. 2.

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