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PRELIMINARY RESULTS OF A GAMMA-RAY BURST STUDY IN THE KONUS EXPERIMENT ON THE VENERA-11 AND VENERA-12 SPACE PROBES

Ye. P.Mazets, S.V. Golentskiy, V.N. Il'inskiy, V.N. Panov, R.L. Aptekar', Yu.A. Gur'yan, I.A. Sokolov Z.Ya. Sokolova, T.V. Kharitonova

Translation of "Predvaritel'nyye Reszultaty izucheniya gamma-vspleskov v eksperimente "konus na AMS 'Venera-11' i 'Venera-12'," Leningrad, Academy of Sciences USSR, A.F. Ioffe Physical-Technical Institute, Report No. 599, 1979, pp 1-31

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16. Abstract

Twenty-one γ-ray bursts and 68 solar flares in the hard X-ray range have been detected on Venera-11 and Venera-12 space probes during the initial 50-day observation period. Major characteristics of the equipment used and preliminary data on the temporal structure and energy spectra of the γ-ray bursts are considered. The pattern of γ-ray burst frequency distribution vs. intensity, N(>S), has been established.

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PRELIMINARY RESULTS OF A GAMMA-RAY BURST STUDY IN THE KONUS EXPERIMENT ON THE VENERA-11 AND VENERA-12 SPACE PROVES

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Annotation

Twenty-one γ-ray bursts and 68 solar flares in the hard X-ray range have been detected on Venera-11 and Venera-12 space proves during the initial 50-day observation period. Major characteristics of the equipment used and preliminary data on the temporal structure and energy spectra of the γ-ray bursts are considered. The pattern of γ-ray burst frequency distribution vs. intensity, N(>S), has been established.

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I. Introduction

In the first years after discovery of bursts of gamma-radiation with cosmic intensity by Klebesadel, Strong and Olson, the study of this new astrophysical phenomenon was limited to observations on a number of spacecraft of the more intense events occurring no oftener than ten times a year. As a rule, there was no equipment on the satellites especially designed for these observations and the comparative study of the recorded gamma-bursts was difficult because of large differences in the level of sensitivity, energy range, spectral and time resolution of the instruments. Nevertheless, common characteristics of the phenomena were established and the results of the studies made were considered in a number of references, for example [2-5].

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

The nature of the gamma-bursts remains completely unclear. Many hypotheses have been advanced as to the nature of the sources and the mechanism of generation of the radiation. General reviews of theoretical models of gamma-bursts are found in references [5,6]. However, inadequate determination of the experimental situation does not permit even making a correct selection between galactic and metagalactic models. Up until now no reliable identification of the sources of gamma-bursts has been made with definite astrophysical objects; the establishment of galactic or, on the other hand, metagalactic localization of sources of gamma-bursts can be done on the /4
basis of the study of statistical distribution of the frequency of appearance of the bursts depending on their intensity N(S) and angular resolution of the sources on the celestial hemisphere. Recent results of observation of weak gamma-bursts on satellites [7] have served as adequately reliable evidence of the deviation in the relationship N(>S) from the law $S^{-3/2}$, characteristic for a case of uniform and unlimited distribution of sources in space.

In this work, certain preliminary results of observations are presented of gamma-bursts on the Venera-11 and Venera-12 space probes using the Konus equipment especially designed for this purpose.

2. Observation Methods

At the experimental levels it is obvious that the exemplary rates of obtaining new information on gamma-bursts can be achieved only by the use of specialized equipment with high sensitivity which must permit not only recording the weakest but also the more frequent gamma-bursts and as well to measure the time course and spectral composition of radiation with the required degree of detail. This requirement is fairly completely met by the Konus equipment which we developed.

A characteristic negative feature of the equipment mainly determining its structure and method of measurement is the possibility of autonomous determination of direction to the source of radiation when recording bursts on a single spacecraft. This possibility considered in reference [8] is based on the use of a system of gamma-radiation detectors with an anisotropic angle of sensitivity which a single-valued function of the angle of incidence θ of plane flow F to the detector. There are six detectors in the instrument whose axes are directed in positive and negative directions on the axis of the detector's system of coordinates. The NaI(Tℓ) crystal is a separate detector with diameter 80 and height 30 mm. The side and rear surfaces of the crystal are screened in such a way that for a relatively soft gamma radiation of 50-150 keV in a broad range of θ angles corresponding to $\cos\theta = \mu > 0.2$, the difference in functions of sensitivity $f(\theta)$ from μ is small and consequently, $\mu/f(\theta) = \Psi(\theta) \approx 1$. Figure 1 shows the relationship of $f(\mu)$ and $\Psi(\mu)$ calculated for gamma radiation in a range of 50-150 keV with a spectrum $\alpha E^{-1.5 \div -2.0}$ on the basis of the data of experimental calibration of monoenergy radiation with energies 22, 33, 60, 88, 122, 510 and 660 keV. /5

It is obvious that in a general case, the gamma-burst will be recorded by any three detectors and the excess of calculations on the background for them is $N_i = \varepsilon F S_0 f(\mu_i)$, where i is 1, 2, 3 -- the number of detectors, ε -- is the effectiveness at normal radiation incidence, and S_0 -- is the area of the detector. The position of the source of gamma-bursts is prescribed by directional cones μ_i which are determined by the system of equations,

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$$\mu_i = \frac{N_i \Psi_i}{\sqrt{\sum_{i=1} N_i^2 \Psi_i^2}} \text{ when } \sqrt{\sum_{i=1}^{3} N_i^2 \Psi_i^2} = N_0 = \varepsilon F S_0 ,$$

easily solved by an iteration method. The precision of calculation of the values of μ_i and, consequently, of the angles θ_i

is determined by statistical precision of the number of calculations in a detector during the event and the precision of determination f(μ) for calibration. It is easy to indicate that

$$\delta^2(\theta_i) = \frac{N_i^2\psi_i^2}{N_0^2 - N_i^2\psi_i^2}\left[\frac{N_i^2 - 2N_i^2\psi_i^2}{N_i^2}\delta^2(N_i\psi_i) + \delta^2(N_0)\right],$$

$$\delta^2(N_i\psi_i) = \delta^2(N_i) + \delta^2(\psi_i),$$

$$\delta^2(N_0) = \frac{\sum_{i=1}^{3} N_i^4\psi_i^4\delta^2(N_i\psi_i)}{N_0^4},$$

but $\delta(N_i)$ and $\delta(\Psi_i)$ -- are relative precision of measurements N_i and Ψ_i. For gamma-bursts with intensity $2\cdot10^{-5}$ - $2\cdot10^{-6}$ /6
erg/cm² in the 50-150 keV range, $\sigma(\delta) \approx$ 1-4°.

Determination of the direction of incoming radiation of a gamma-burst is illustrated in drawing 2. It is clear that

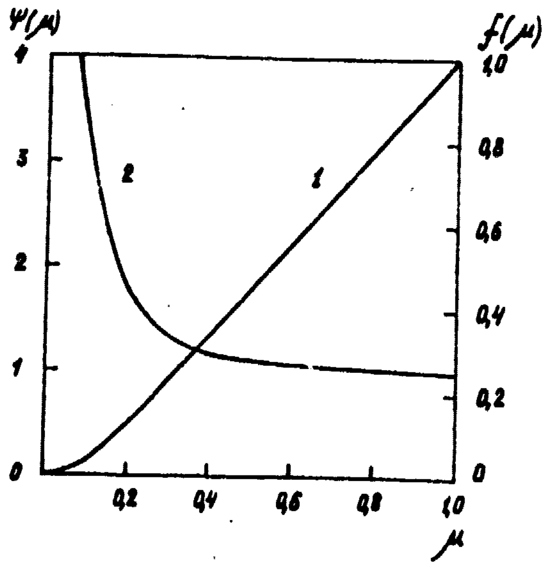

Figure 1. Functions of f(η) (curve 1) and Ψ(η) (curve 2) for radiation with a spectrum $E_\gamma^{-1.5-2.0}$ in the 50-150 keV range.

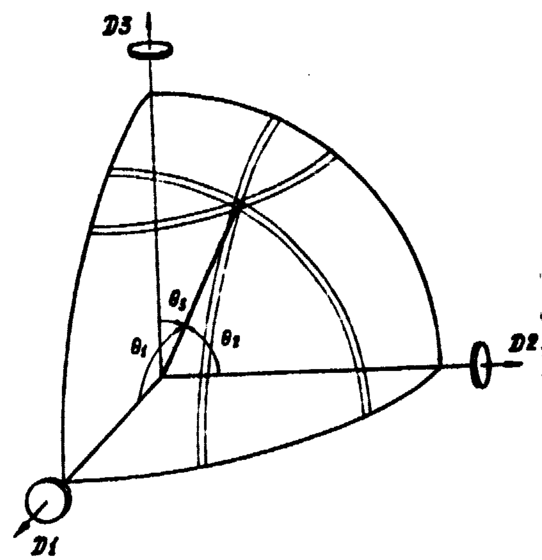

Figure 2. A diagram for determining the direction of the source of gamma-burst according to the readings of 3 detectors (D_1, D_2, D_3).

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with a similar method it is easy to obtain the appropriate expressions for calculating the angles and their errors in any other system of coordinates, for example, in a spherical system (θ,ϕ). We note that the use of readings of only two detectors gives us a value of the azimuthal angle ϕ.

Besides a detector system, the instrument contains a system of six cells for observation of gamma-bursts on the observed level of the background, a system of measurement of time for processing the cells generating the bursts, six counters for measuring the values of N_i, and temporary analyzer with 320 channels, an amplitude analyzer with 128 channels, logic and certain auxiliary devices. The instrument operates in a slave state where, using six counters, the background is periodically measured in each detector in the 50-150 keV range using the amplitude analyzer -- differential energy spectra of the background in a range of 30 keV - 2 MeV. Calibration of the instrument is controlled along the 0.511 meV line in the background spectra. During the appearance of the gamma-burst, the detection device sends command signals which are analyzed by the logic instrument. As a result, the time and amplitude analyzer is switched on and the detector which has the greatest sensitivity for the gamma-burst source. The prehistory of the burst is recorded for eight seconds in the time analyzer, recorded with a resolution of 0.25 s and fixed by the temporary path of the burst for a period of 2 s with a resolution of 15.625 ms; then, for 32 s with a resolution of 0.25 s and later on for 32 s with a resolution of 1 second. The amplitude analyzer has 16 channels with a quasilogarithmic scale and 8 energy spectra are measured in 8 sequential intervals of 4 seconds each. The system of counters measures the counting rate in each detector for the first 4 seconds and the succeeding 12 seconds. The time course of the burst is fixed to onboard time with a precision of ± 1 s. /7

Recording of the gamma-bursts for two or more spacecraft makes it possible to obtain information on the direction of the radiation source also by a triangulation method according to the time of relative lag of the incoming burst. We plan to present a more complete description of the equipment and method of measurement in a separate work; here we will discuss in more detail only the observation cell for the gamma-burst. Generation of the burst is in a range of 50-150 keV which, in our opinion, is close to optimum in relation to the value of the effect-background. The instrument is similar and contains three quasilogarithmic ratemeters with effective time constant 0.3, 1.5 and 30 s. The last ratemeter is the reference meter and levels of the first (for short bursts) and the second (for longer bursts) are compared with its output level. An excess in the level of one of the signal ratemeters over the reference meter by a value $\approx 6\sigma$ of the actual background results in the appearance of a command signal for recording of the burst. The working level of $\approx 6\sigma$ is maintained automatically in the range of background values from 50 to 10^3 pulses per second.

Figure 3 shows the calibrated curve of sensitivity of the equipment for a case of recording a square burst of gamma-radiation in a range of 50-150 keV with different duration T at a background level $\sim$ 100 pulse/s. The graph visually demonstrates the increase in the threshold of recording with an increase in duration of the burst. This circumstance, being primary for the generation of a pulse signal on a fluctuating background results in discrimination of longitudinal bursts and, as a result, in unavoidable observation selection [7]. The use of two signal ratemeters with a different time constant decreases the sharpness of the curve of relationship S(T) with an increase in T and provides at the same time noticeable weakening of discriminations of longitudinal bursts while retaining high sensitivity to a short burst. With an average background level, in conditions of actual observations,

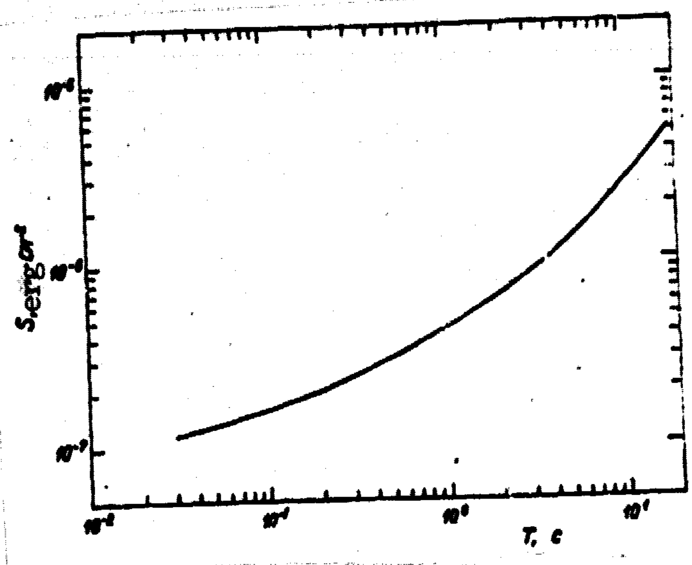

Figure 3. The dependence of the threshold of recording of a gamma-burst with square shape on its duration T.

about 100 pulses per second, the threshold sensitivity of the instrument in relation to the short burst is $(3-5) \cdot 10^{-7}$ erg/cm^2. /8

3. Observation results

The Konus equipment was installed on the two Venera-11 and Venera-12 space probes launched at the beginning of September, 1978. For the observation period considered here lasting 50 days, the equipment recorded and measured 21 gamma-bursts, 68 solar flares in hard X-ray range and 9 simulations. For 29 days of simultaneous operation of stations, 12 bursts were observed. Of these, 2 weak gamma-bursts whose intensity was close to the recording threshold were fixed only on the Venera-11.

The information obtained permits distinguishing very easily between solar flares and gamma-bursts even in cases

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where the equipment works only on one station. In the first place, when there are solar flares, only one detector operates, the one directed at the sun. In the second place, the soft energy spectra of radiation of flares differs sharply from the gamma-burst spectra. The effectiveness of this simple criterion is fully supported in cases of recording radiation of solar flares on both stations. Simulations are brief with an exponential drop, single bursts characterizing a very soft spectrum. They are observed only in one of the detectors. The most probable cause of such simulation is phosphorescence in NaI(Tℓ) crystal excited by large losses of energy in the detector when multicharge particles of cosmic radiation pass through it or when there is nuclear splitting [9].

The list of recorded gamma-bursts, the time for starting to record T_0, intensity S in the ranges $E_\gamma > 30$ keV and $E_\gamma >$ 150 keV are presented in the table. The values of S are obtained on the basis of measurements of differential spectra in each case F(E). The values of S (> 150 keV) are presented for convenience in comparing them with observation data on the Vela satellites [2]. It follows from the table that for most of the events, a considerable part of the gamma-burst energy is contained in the soft part of the spectra at an energy of $E_\gamma < 150$ keV. /9

The temporary structure of the gamma-bursts is characterized by great differences. Figures 4-8 show temporary profiles of certain events constructed for intensity of radiation in a range 50-150 keV with an average at $\Delta t = 1/4$ s. Separate points in front of the continuous histogram at $t < T_0$ is the recording of the prehistory of the burst for a given detector. Such data indicate that many gamma-bursts are characterized by a comparatively slow increase in intensity at onset. For most of the weak gamma-bursts observed, the statistical provision of the recording of the temporary course with a resolution of 1/64 s

Table: Cosmic Flares of Gamma Radiation Recorded on the Venera-11 and Venera-12 Space Probes /10

No.	Date			S (> 30 keV), erg/cm^2	S (> 150 keV) erg/cm^2
		Venera -11	Venera-12		
I	I4/IX-78	II.42.46	No information	$9,2\cdot10^{-6}$	$1,5\cdot10^{-6}$
2	I4/IX-78	I6.42.I2	-"-	$1,7\cdot10^{-5}$	$5,5\cdot10^{-6}$
3	I6/IX-78	No information	I0.03.26	$4,6\cdot10^{-6}$	$2,9\cdot10^{-6}$
4	I8/IX-78	I9.49.II	No information	$2,8\cdot10^{-5}$	$1,8\cdot10^{-5}$
5	2I/IX-78	03.55.55	-"-	$1,8\cdot10^{-5}$	$1,1\cdot10^{-5}$
6	2I/IX-78	20.22.04	-"-	$1,0\cdot10^{-6}$	$3,0\cdot10^{-7}$
7	22/IX-78	I2.34.06	-"-	$2,1\cdot10^{-6}$	$9,3\cdot10^{-7}$
8	30/IX-78	06.47.24	06.47.2I	$1,8\cdot10^{-5}$	$9,0\cdot10^{-6}$
9	4/X-78	00.47.I9	Not recorded	$6,0\cdot10^{-7}$	$3,0\cdot10^{-7}$
I0	5/X-78	00.50.25	00.50.20	$6,3\cdot10^{-6}$	$2,7\cdot10^{-6}$
II	6/X-78	I0.59.50	I0.59.52	$2,6\cdot10^{-5}$	$1,8\cdot10^{-5}$
I2	6/X-78	I4.25.I9	I4.25.I7	$1,7\cdot10^{-5}$	$1,1\cdot10^{-5}$
I3	II/X-78	I0.52.33	Not recorded	$1,3\cdot10^{-6}$	$3,0\cdot10^{-7}$
I4	I2/X-78	0I.I6.2I	0I.I6.2I	$9,3\cdot10^{-6}$	$4,4\cdot10^{-6}$
I5	I2/X-78	I7.I3.49	I7.I3.47	$4,0\cdot10^{-6}$	$2,6\cdot10^{-6}$
I6	I3/X-78	I4.54.4I	No information	$1,1\cdot10^{-6}$	$6,0\cdot10^{-7}$
I7	22/X-78	23.24.32	-"-	$2,0\cdot10^{-6}$	$6,0\cdot10^{-7}$
I8	23/X-78	I7.23.35	-"-	$6,7\cdot10^{-6}$	$4,8\cdot10^{-6}$
I9	25/X-78	23.54.00	23.53.56	$4,0\cdot10^{-6}$	$2,5\cdot10^{-6}$
20	26/X-78	08.03.49	08.03.53	$1,7\cdot10^{-5}$	$1,0\cdot10^{-5}$
2I	2/XI-78	I2.33.30	I2.33.32	$2,6\cdot10^{-6}$	$6,0\cdot10^{-7}$

[Commas in the tabulated material are equivalent to decimals.]

is not great and such data will not be presented here. However, /9 figure 9 indicates that the gamma-burst on 11/2/78 is characterized by a very sharp initial pulse during which the power at the source is generated significantly exceeding the mean value for the subsequent phase of the burst. From a recording of a burst with a resolution 1/64 s (figure 10) it follows that the initial pulse lasts for less than 15 ms and the power of radiation in it exceeds the average by almost 30 times. The fine characteristics of operation of the time analyzer make it possible to show that duration of the initial pulse in this burst does not exceed 9 ms.

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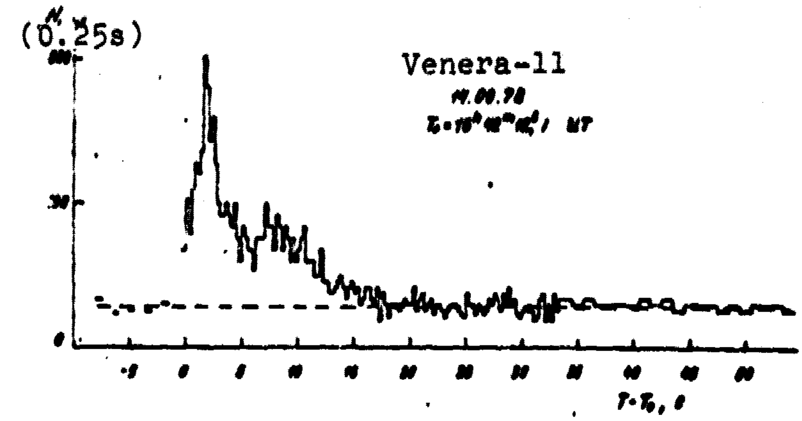

Figure 4. Gamma-burst 9/14/78 is characterized by relatively slow increase and drop in intensity of radiation. Dashed line is the background level.

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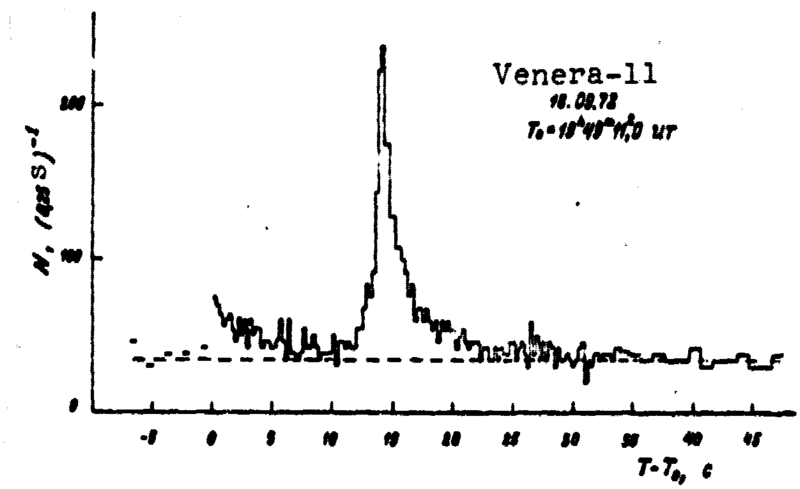

Figure 5. In a burst 9/18/78, the main phase increases every 15 s after onset.

In figures 11-15, the energy spectra of certain gamma-bursts are shown. These graphs demonstrate that the spectra of gamma-radiation of bursts can differ noticeably; however, one observes events with practically uniform spectra (figure 12). For certain bursts, noticeable changes of the spectra are detected with time. Figure 13 shows combined spectra of gamma-bursts on 9/14/78 measured at the 1st, 3rd and 4th sequential 4-second intervals of time after T_o. The graphs clearly show /9

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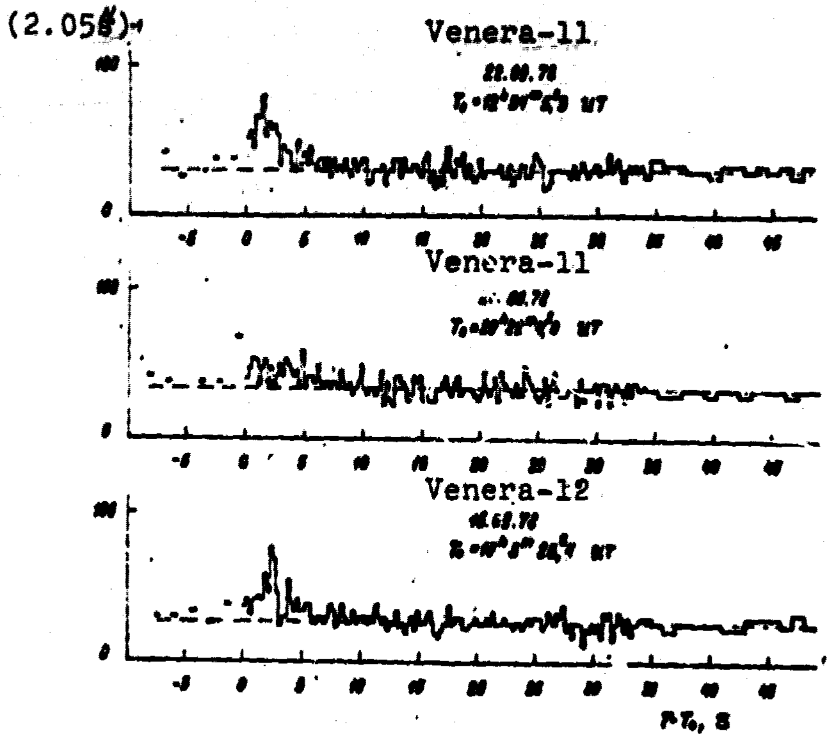

Figure 6. Examples of recording weaker gamma-bursts with average duration. The intensity of the burst 9/21/78 is close to the threshold of observation.

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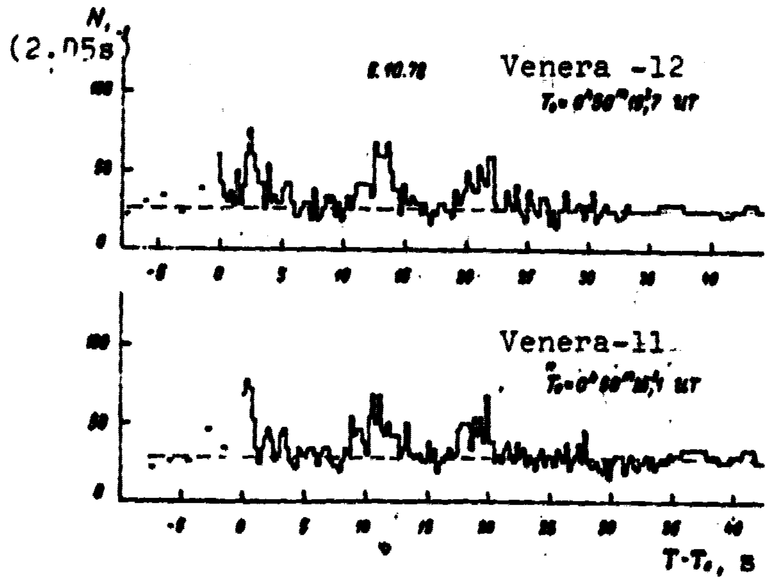

Figure 7. Long-term burst in the form of a sequence of several broad pulses with approximately even intensity.

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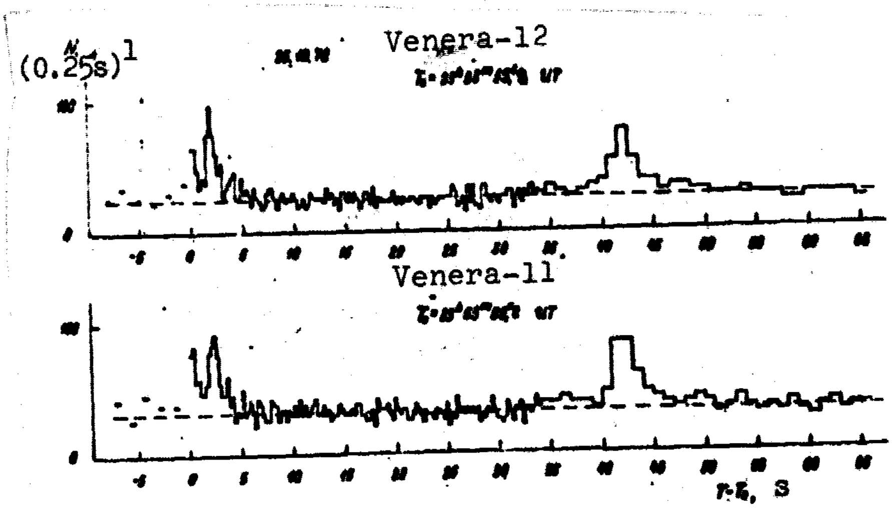

Figure 8. A burst made up of two pulses with diversity ∿ 40 s in the space between which the intensity of radiation drops to the background level. The second pulse is found by operation time of the temporary analyzer with a resolution of 1 s.

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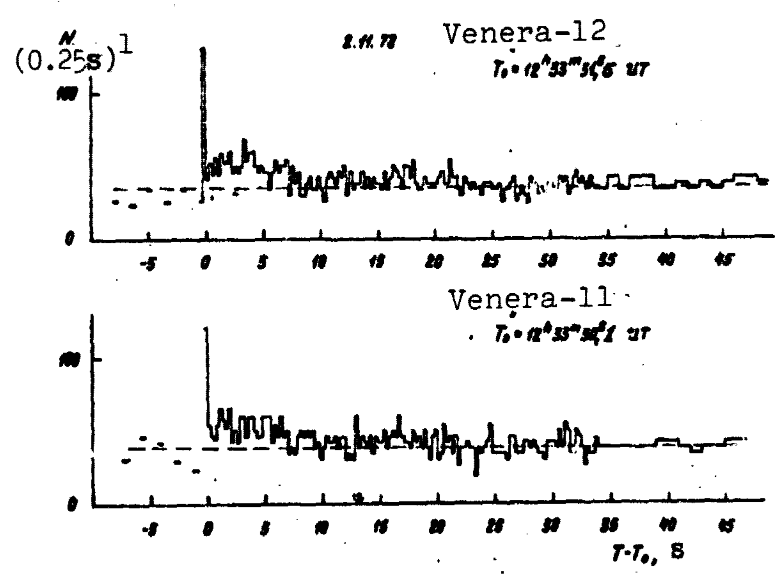

Figure 9. A burst with sharp initial pulse recorded with a resolution of 1/4 s.

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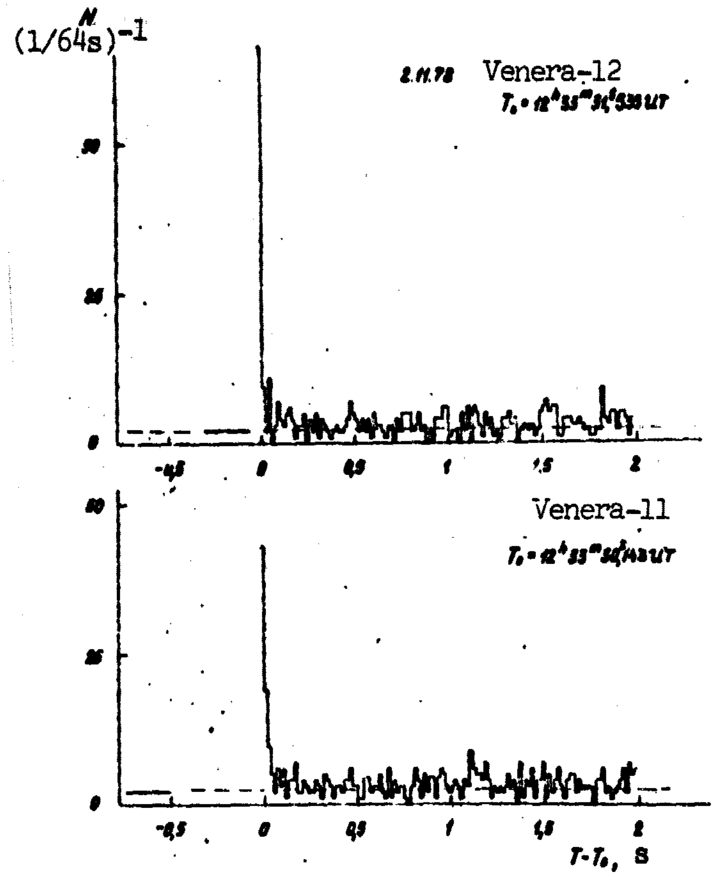

Figure 10. Recording with resolution 1/64 s indicates that the radiation power in the narrow initial pulse exceeds by 30 times the average power for the subsequent phase of the burst.

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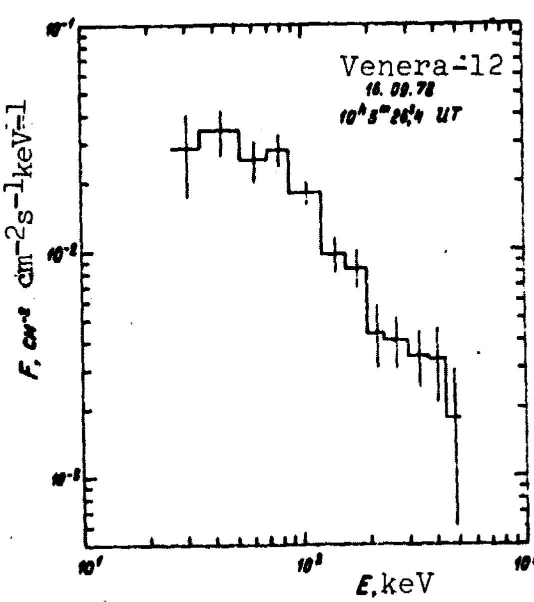

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Figure 11. Energy spectrum of a gamma-burst 9/16/78

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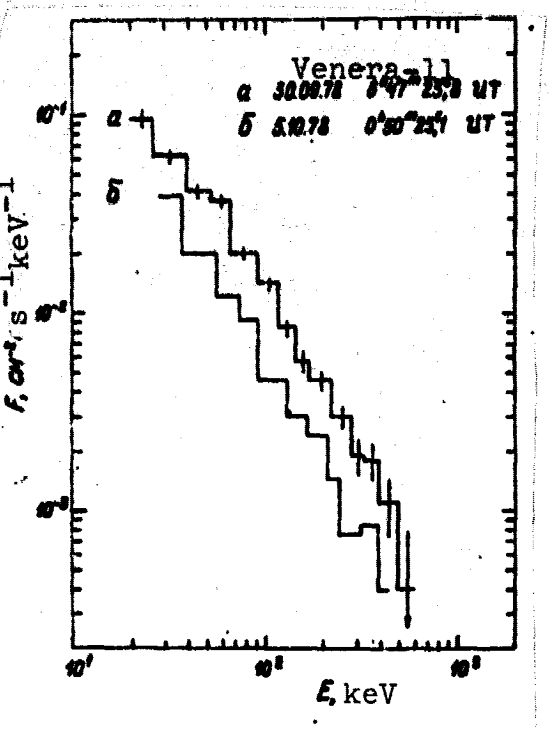

Figure 12. Energy spectra of 2 gamma-bursts close in shape

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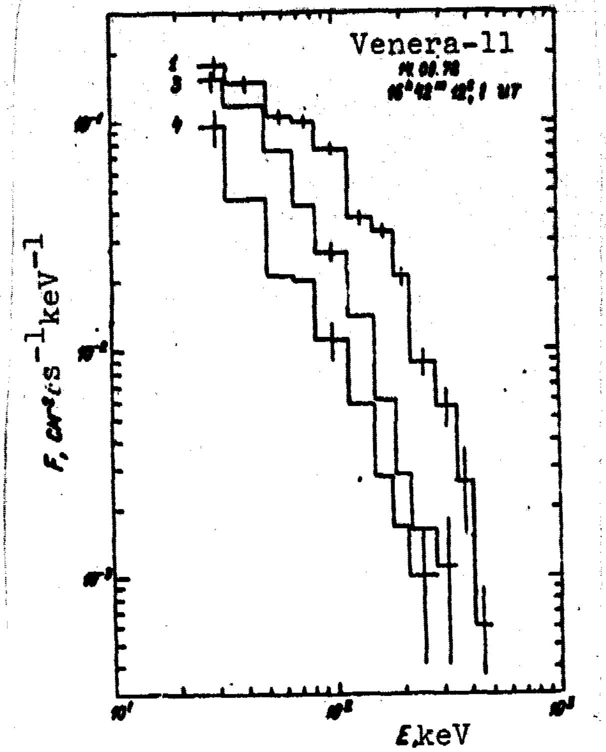

Figure 13. An example of observation of the evolution of the radiation spectrum during a burst. Spectra are presented measured in the 1st, 3rd and 4th 4-second intervals after T_o.

that the spectrum of gamma-radiation, exponential at first, /9
at the end of the burst is changed in degree and the radiation as a whole becomes softer.

Spectra of gamma-radiation of bursts shown in figures 14 /12
and 15 lead one to assume that in the 300-400 keV region one observes an excess of radiation which could involve the presence of monoenergetic components in the spectrum. Although statistical precision of the data considered is inadequate for fully defined proof, the large similarity of two sequentially measured spectra (4 and 5) for the main pulse of the gamma-burst on

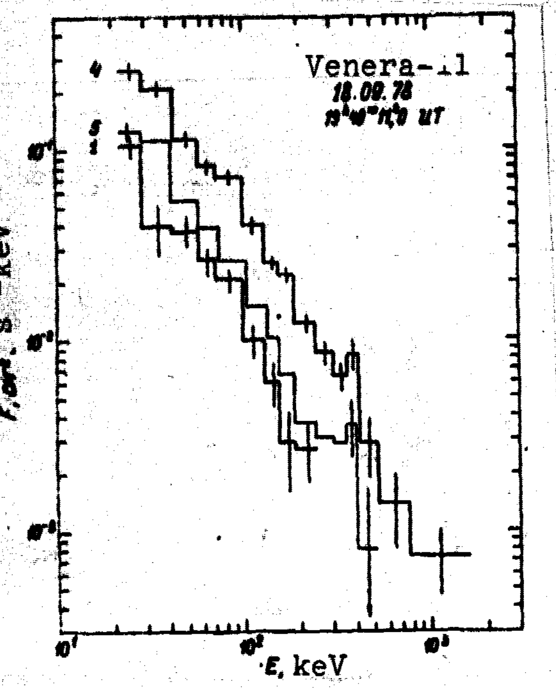

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Figure 14. Spectra of a gamma-burst 9/18/78 measured at the 1st, 4th and 5th 4-second intervals after T_o. These data lead to the hypothesis that there is an excess component of radiation in the 300-400 keV region.

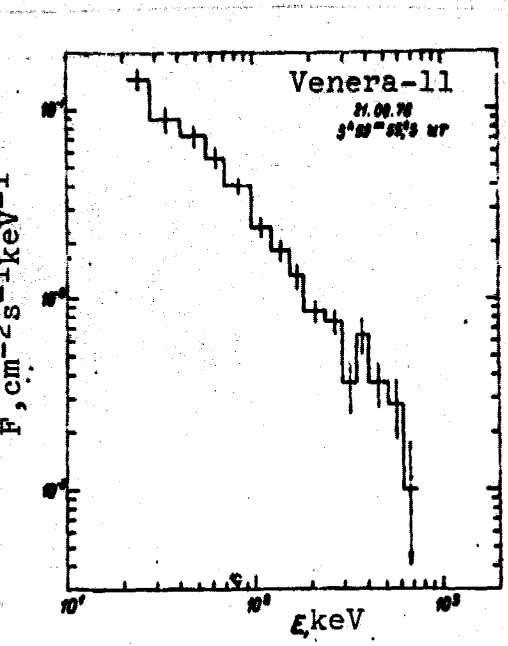

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Figure 15. A spectrum of a gamma-burst 9/21/78 shows a similarity with the spectra of figure 14.

9/18/78 can be considered as some proof of the reality of the /12
characteristics in the spectrum.

As an example of the information obtained we also present the coordinates of the source of a gamma-burst on 9/14/78, $11^h\ 42^m\ 46^s$ UT, obtained with observations from only the Venera-11 probe: $\alpha = 258° \pm 2°$; $\delta = 1° \pm 2°$.

4. Distribution of Frequency of the Manifestations of Gamma-Bursts

The data obtained even in their initial volume permit establishing the type of integral distribution N(>S) of frequency of the

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appearance of gamma-bursts depending on intensity S. In figure 16 on curve 1, the distribution of N(>S) is shown of 21 gamma-bursts constructed according to the data of the succeeding column (S >150 keV) of the table. One should note on the whole good agreement of new data with the results of preceding observations of weak gamma-bursts on the Kosmos-461 and the Meteor satellite [7]. The results of observations on the Vela satellite are shown in curve 3. The internal similarity of these two distributions is not unexpected because the strong decrease in the curve of distribution in the field of smallest values of S is caused by the manifestation of observation selection. The result of introducing corrections on the observation selection $\varepsilon(S)$ according to the method of reference [7] into the experimental data for evaluation of actual distribution $N(>S) = \varepsilon^{-1}(S)N_{obv}(S)$ is presented in figure 16 by the relationships 2 and 4. We note here once more that a calculation of the coefficients $\varepsilon(S)$ with complex and extremely varied time structure of the gamma-bursts can be done only with a number of simplified proposals. Thus, curves 2 and 4 are obtained with the hypothesis that the main part of the burst can /13
be shown by a square pulse with duration $0<T\leq T_{max}\approx 30$-$40$ s. In actuality, in the gamma-bursts, the peak values of the count

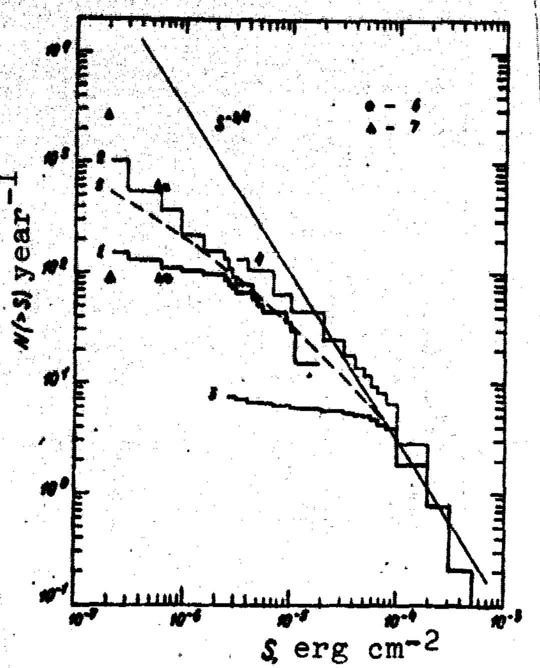

Figure 16. The integral distribution of N(>S) of the frequency of the appearance of bursts depending on their intensity. 1 -- The Venera-11 and Venera-12; 3 -- the Vela; 6,7 (dark marks) -- Cosmos-461 and Meteor; 2,4 and 6,7 (light marks) -- the same data corrected on the observation selection; 5 -- total integral distribution.

rate noticeably exceed the average level and for this reason the degree of selection will decrease. Distributions 2 and 4 must be considered as the upper limits for actual distribution N(>S). With the calculation of these notations curve 5 can be the general evaluation of N(>S).

Here, one should note that the results of an attempt at observations of gamma-bursts with high altitude balloons [9,10] also attest to the breakdown of the relationship $S^{-3/2}$; however, evaluations given by the authors of the indicated works of frequency of appearance of weak bursts lies considerably higher than distribution 5. On the basis of the data obtained with long term observations on spacecraft, we can propose that further experimental precision, apparently, does not lead to a noticeable deviation from the curve 5 presented for distribution. This type of relationship of N(>S) can be considered as a reliable proof of galactic localization of the sources of gamma-bursts if one digresses from consideration of certain metagalactic models with strong evolution of sources [11]. In this connection, obtaining statistically verified data on distribution of sources of gamma-bursts against the celestial sphere acquires great importance.

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