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PHOTOMETRIC AND RADAR OBSERVATIONS OF AN EXCITED ERUPTION IN THE "ZARNITSA-2" EXPERIMENT

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16. Abstract

In a controlled experiment a ground photometer and radar station recorded an increase in night sky luminescence following injection of an electron beam into the atmosphere from a rocket at altitudes 80 to 154 km. A main and supplementary scattering and luminescence regions were observed. The effect is presumed to be due to electron eruption induced by artificial action on the magnetosphere.

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In the controlled Zarnitsa-2 experiment, a ground photometer and radar station recorded an increase of the luminescence of the night sky and additional scattering that appeared during electron injection from the rocket. The luminescence and scattering area was approximately 15 kilometers at a distance of about 20 kilometers from the point where the beam was injected into the atmosphere. It is presumed that the effect was caused by electron eruption excited by manmade action on the magnetosphere. The observed effect is in agreement with a similar effect observed in the Feyerverk experiment.

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Introduction /3*

In the "Feyerverk" experiment carried out in 1973, a ground photometer recorded an increase in night sky luminescence in the 3914Å wavelength, which appeared when high-energy electrons and cold plasma were injected from a rocket. The luminescence area was some 20 kilometers from the point where the electron beam invaded the atmosphere. The effect was explained as being due to excited eruption of captured electrons in the action upon them of excitation forces associated with the injection of the electrons and plasma [1, 2]. Since the electrons and plasma were injected simultaneously it was hard to determine which of the two actions caused the observed effect. Difficulties also arose in determining the relative position of the artificial Aurora beam and the field of view of the photometer.

The controlled "Zarnitsa-2" experiment, one of the purposes of which was further study of the discovered phenomenon, was so planned as to circumvent the difficulties mentioned before. The following presents some results of photometric, radar and on-board measurements performed by the Institute of Space Research, USSR Academy of Sciences, and the Polar Geophysical Institute, USSR Academy of Sciences, in the "Zarnitsa-2" experiment in the course of which a similar effect was observed.

Description of the Experiment /4

The experiment was carried out September 10, 1975, in the median latitudes of the USSR ($L \simeq 2$). A general description of the experiment and the on-board and ground instrumentation involved is presented in [3]. A pulse injection of high-energy electrons was carried out

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

from an MR-12 rocket. The electron accelerator was switched on at the 96th second of flight time, and until the 136th second injected an electron beam with parameters I = 0.38Å, E = 9.3 kev, and then until the injector was switched off at the 316th second, I = 0.45Å, E = 7.2 kev. The injection was carried out on the upward and downward legs in the altitude range 80 to 154 km. The operating cycle of the injector consisted of a long (≈ 0.7 sec) and short (≈ 0.07 sec) pulses separated by a pause of 0.6 sec. Owing to rotation of the rocket, the injection pitch angles varied from 28 to 92°, that is, injection was mainly into the lower hemisphere. The cesium plasma source was switched on in the 235th sec, and for 35 sec it injected a flow of plasma with current 5-10 amperes.

The following scientific instruments were also on board the rocket: Volt-M electron sensor, Ushba-M electron spectrometer, Volna radio emission receiver, Polye potentiometer.

The earthbound instrument complex included highly sensitive television units, modulation photometers, radar stations, radio emission receivers, and other instruments.

A number of organizations took part in preparing and carrying out the experiment. The work was coordinated by the USSR Academy of Sciences' Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation, science supervisor of the experiment was I. A. Zhulin.

a) Photometric Observations /5

The radiation receiver was, as in the "Feyerverk" experiment, a modulation photometer with a rotating inteference filter [4]. To determine the position of the field of view of the photometer relative the artificial Aurora beam, the photometer was mounted on the same swivel device as a highly sensitive television camera. The field of view of the photometer was set and secured relative the television camera. This type of mounting possessed a number of advantages over both a photometer and a television system and in effect made it possible substantially to enhance the quality of measurements. For example, a photometer, with which subtle physical measurements can be carried out, has a major drawback: it does not provide an image of the radiation source. And the latter's configuration can substantially affect the accuracy with which the intesnity of the observed luminescence is determined. On the other hand, with a television system it is difficult to carry out photometric measurements. Combining a television system with a photometer overcomes the shortcomings of each instrument. The television camera was provided with an image orthicon with an EOP (LI-217) and had a sensitivity ≈ 9.25 stellar magnitude at 0.2 sec exposure and field of view 30x20°.

The photometer recorded radiation at wavelength 3914 Å, the strongest band in the first negative system N_2^+. There is no radiation on this wavelength in the spectrum of night sky luminescence, and it is associated directly with atmospheric ionization by high-energy electrons. Photometer sensitivity was 5R at 5° angle of vision and time constant 0.1 sec.

Orientation of the photometer was set so as to keep the beam of /6
artificial Aurora from entering its field of vision. The high sensitivity of the television system made it possible to observe the beam virtually throughout the whole flight and to determine the position of the photometer's field of vision with respect to it by processing the pictures.

b) Radar Observations

Auroral scattering of radio waves on a domain of heightened radiation caused by the invasion of a man-injected beam of electrons was first observed in the "Zarnitsa-1" experiment [5]. The measurements made it possible to determine the inclination distance and the effective scattering diameter, and the temporal characteristics of the scattering process.

In the "Zarnitsa-2" experiment radiophysical effects were observed with the help of radar stations in the meter band on frequencies 44 and 85 MHz, at sounding pulse duration 8 μs. The observation point was chosen so as to assure optimum angle conditions, and it was located relative the launching position as shown in Fig. 1 (point B). The antennas were stationary and oriented on the area of expected invasion of injected electrons. Fig. 1 shows isolines of equal angles of vision and the projection of the region of invasion of injected electrons on the horizontal plane calculated for the altitude 110 km. The width of the direction diagram in the horizontal plane was 12° (44MHz) and 22° (85 MHz), which made it possible to observe the expected effects from the whole region into which electrons were injected.

Radar observations were also conducted from two more points /7
by teams from the Polar Geophysical Institute and the Kiev State University.

c) On-Board Observations

A Volt-M sensor was carried in the rocket to measure the electron flux. The sensor represented a miniature Gieger counter mounted over a bismuth reflecting spacer. The geometry expanded the instrument's field of vision virtually to 2π on average[1]. At electron energy equal to 30 kev, the sensor had a sensitivity of $2\cdot10^{1}$ el$\cdot$cm^{-2} sec^{-1}; at energies below 10 kev the sensitivity decreased by 4 orders of magnitude. The instrument was mounted under the electron injector, as shown in Fig. 2, and it registered electrons with pitch angles 0-120°, that is, mainly electrons coming from the upper hemisphere.

Experimental Results

Fig. 3c presents a record of photometer readings as a function of flight time. An increase in the intensity of night sky luminescence to 20 rels occurs in the 108th sec, 12 sec after injection; for 23 sec mean intensity is [illegible] rels, then drops to background value; 10 sec later, in the 151st sec, it rises to a mean of 12 rels for 30 sec. Then to the end of the experiment the intensity decreases monotonously, without, however, reaching its initial value.

Fig. 4 presents a view of a television frame at the 115th sec, when an increase in night sky luminscence was observed. It can be seen that the beam of artificial Aurora does not come into the field of vision of the photometer, and the point of maximum penetration into /8

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[1] Suggested by V. N. Lutsenko and N. Yu. Svechnikov

the atmosphere is at distance X and Y from the field of view of the photometer. The change in the values of X and Y as a factor of flight time is shown in Fig. 3d. It can be seen that throughout the experiment the beam did not enter the field of vision of the photometer (the squares and crosses indicate the transfer times of the photometer and T.V. system, when their orientation changed sharply. The curve was obtained after processing the photographs made from the T.V. screen.). Proceeding from the values of X and Y we can evaluate the distance between the field tube used for the electron injection and the region of additional luminescence. Assuming the maximum intensity of luminescence to lie between altitudes 90 and 120 km, the distance is 20-30 km. To compare radar measurements with photometric data, Fig. 1 shows the horizontal projection of its field of vision at 110 km at three consecutive instants (110, 160, 180 sec).

The radar, operating at a frequency of 44 MHz, registered, besides the principal reflecting region associated directly with the operation of the electron injector, the appearance of an additional region. It was at least 10 km long and was "washed out", reflections from it being diffuse in character. The distance of the additional region from the observation remained virtually unchanged and was approximately 322 ± 6 km. The distance of the main region, on the other hand, increased rapidly, due to the injected beam receding from the observation point (because of the motion of the rocket). The change in distance of the principal and supplementary regions is shown in Fig 3a. It can be seen from Fig. 1 that the position of the inclination /9 distance at which the supplementary scattering was observed (curves 2 and 3, which correspond to scattering in regions at altitudes 115 and 100 km) coincides with the position of the field of view of the photometer at the 110th and 160th seconds, that is, at the times when the luminescence was observed.

Until 130 sec of flight time the supplementary and main regions were superimposed in the indicator (their inclination distances coincided or were very close), and only after 130 sec were they observed separately. The time of appearance of the supplementary region can, apparently, be set at the instant of sharp reduction of the inclination distance to the leading front of the reflected system, which was observed between 109 and 110 sec. We note that this time coincides to an accuracy of 1 with the appearance of the luminescence. More accurate determination of the time of appearance of the supplementary scattering is difficult owing to the superimposition on the scattering signal of radiation on the radar frequency that appears when a beam of electrons is injected. The initial intensity of reflection from the supplementary was almost 10 dB above the detection threshold. In the 150th sec, the level of the signal decreased rather sharply, and after 205 sec it could no longer be distinguished against the background. Fig. 3b shows the variation in the intensity of reflections from the supplementary region. To plot the dependence, micrometering was carried out of the film recording of the observation results with the help of a brightness indicator.

In flight, the Volt-M sensor, in addition to the counting associated with electron injection [6], registered the background count of natural electrons with intensity ≈0.15 counts/sec. Using data [6] /10 on the form of the electron energy spectrum at these altitudes and the energy dependence of the sensitivity, it can be established that the main contribution to the count is made by electrons having energy $\gtrsim$30 kev. The value of their flux, $5\cdot10^2$ $cm^{-2}\cdot sec^{-1}$, is in agreement with data cited in [6] for quiescent geomagnetic conditions. Beyond the limits of the statistic the flux of erupting electrons had no variations that could identified with the appearance of supplementary scattering and luminescence.

Discussion of Results

Thus, an analysis of photometric data indicates the appearance of a radiating region separated from the point of injection of the electron beam into the atmosphere. The luminescent region coincides in inclination distance with the region of supplementary scattering, is located within the width of the direction diagram of the radar station, and satisfies angle-of-vision conditions. The supplementary scattering appears not later than 1 sec after the increase in luminescence intensity and continues, like the luminescence, until the 200th sec. The fact that the radiating region and region of supplementary scattering coincide in time and space make it possible to assume that they are identical, while the fact that the radiation was observed at wavelength 3914 Å leads to the conclusion that the effect is due to the appearance of supplementary ionization, that is, the invasion of high-energy electrons. The magnitude of the energy flux of the erupting electrons, which can be determined from the observed intensity of luminescence, is $\approx 5 \cdot 10^{-2}$ erg·cm^{-2}sec^{-1}.

An electron flux at energy 30 kev and the given intensity could /11 be recorded by the Volt-M sensor. The absence of any count increase is apparently indicative of localization of the eruption, which is also confirmed by photometric and radar data, although this cannot be asserted definitely (at 1-10 kev energy a flux of above intensity is below the instruments threshold).

The approximate size of the scattering and luminescence region, according to radar data, is ≈15 km along the line of vision.

As in the "Feyerverk" experiment, the elecron eruption effect is caused by artificial action on the earth's magnetosphere. Unlike that experiment, it can be said that the observed phenomenon is caused by the injection of electrons rather than plasma. It can also be assumed that the eruption is caused by cyclotron interaction of whistler type plasma waves appearing with the injection of an electron beam with electrons captured in the magnetosphere (diffusion in the loss cone [7,8]). A detailed study of wave phenomena accompanying electron beam injection was carried out in the "Echo-11" experiment [10, 11]. The measurements indicated a strong dependence of the wave amplitude on the injection pitch angle, which increases with the angle. This can explain the delay in the eruption with respect to the beginning of the injection observed in our experiment. Owing to precession of the rocket, the range of injection pitch angles in one rotation of the rocket changes with time, as shown in Fig. 3e; from 108-110 sec injection was also carried out at pitch angles exceeding 90°, in which case the wave amplitude should increase sharply. We note that a similar dependence of eruption intensity was observed in the "Feyerverk" experiment, when the magnitude of luminescence /12 decreased when injection was into a subrocket point [2].

Not wholly understandable is the absence on data indicating eruption after 200 sec of flight, when electron injection continued, and the absence of any displacement of the eruption region in the wake of the rocket displacement.

It would be interesting to compare the presented data with the results of radar observations at the other two radar locations.

Thus, in the "Zarnitsa-2" experiment eruption induced by artificial injection of electrons was recorded by two independent methods: photometric and radar. The result confirms the effect observed in the "Feyerverk" experiment, and studying them jointly will make it possible to investigate the phenomenon in greater detail.

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FIGURE CAPTIONS

Fig. 1. Schematic representation of the experiment projected on the horizontal plane. A - Starting point; B - Point of optical observations; V - Rocket path; 1 - Region of beam invasion; 2, 3 - Inclination distance to supplementary scattering region.

Fig. 2. Location of the electron accelerator (2) and Volt-M sensor (1) on board the rocket; 3 - Electron beam.

Fig. 3. Radar and photometric data as a function of flight time:
a - Inclination distance to main and supplementary regions;
b - Intensity of scattered signal from supplementary region;
c - Intensity of luminscence on wavelength 3914 Å;
d - Distance between artificial Aurora beam and photometer field of vision; e - Change in pitch-angle injection range.

Fig. 4. Television screen image at 110th sec. Hatched area is the photometer field of vision.

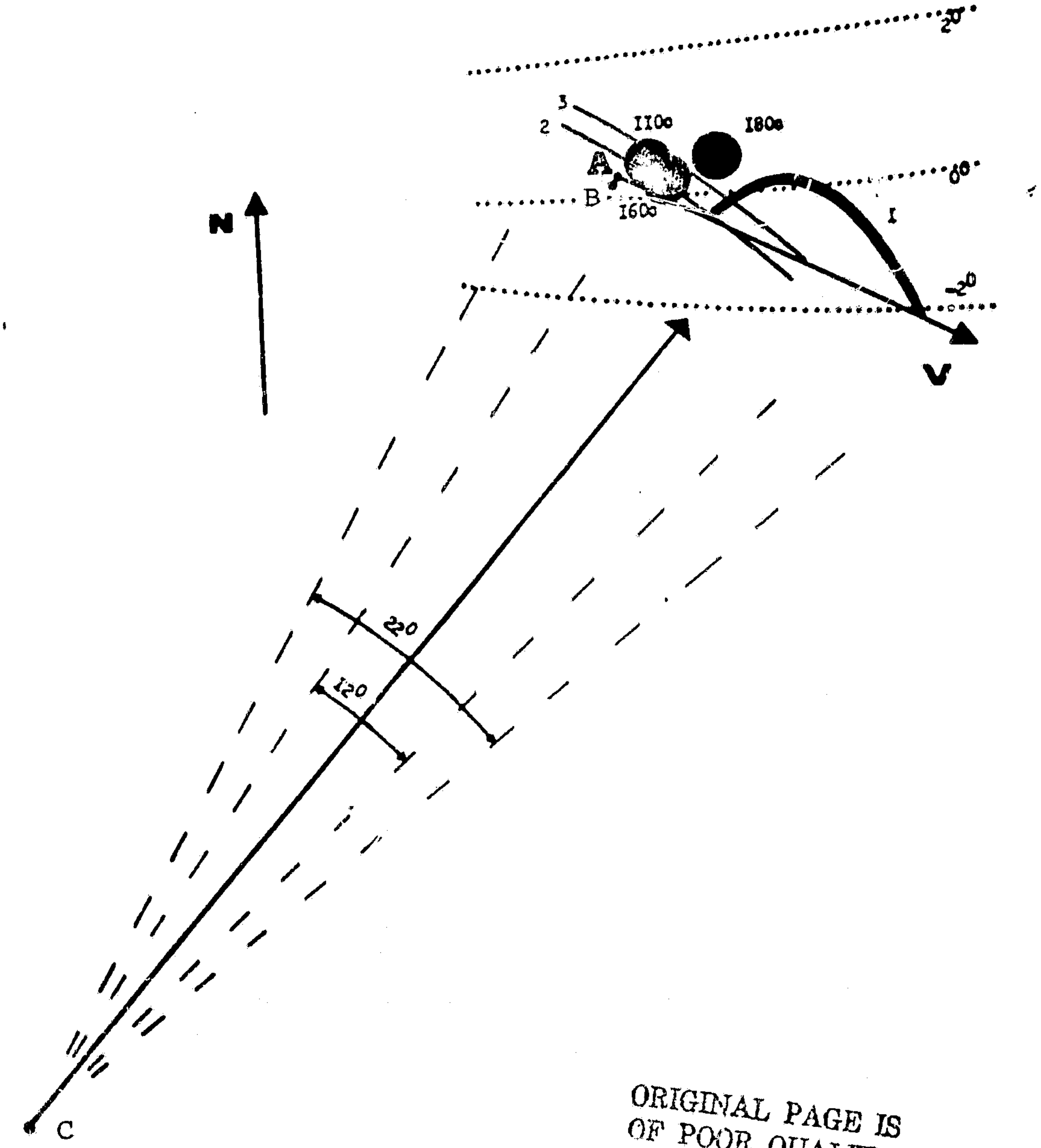

Fig. 1

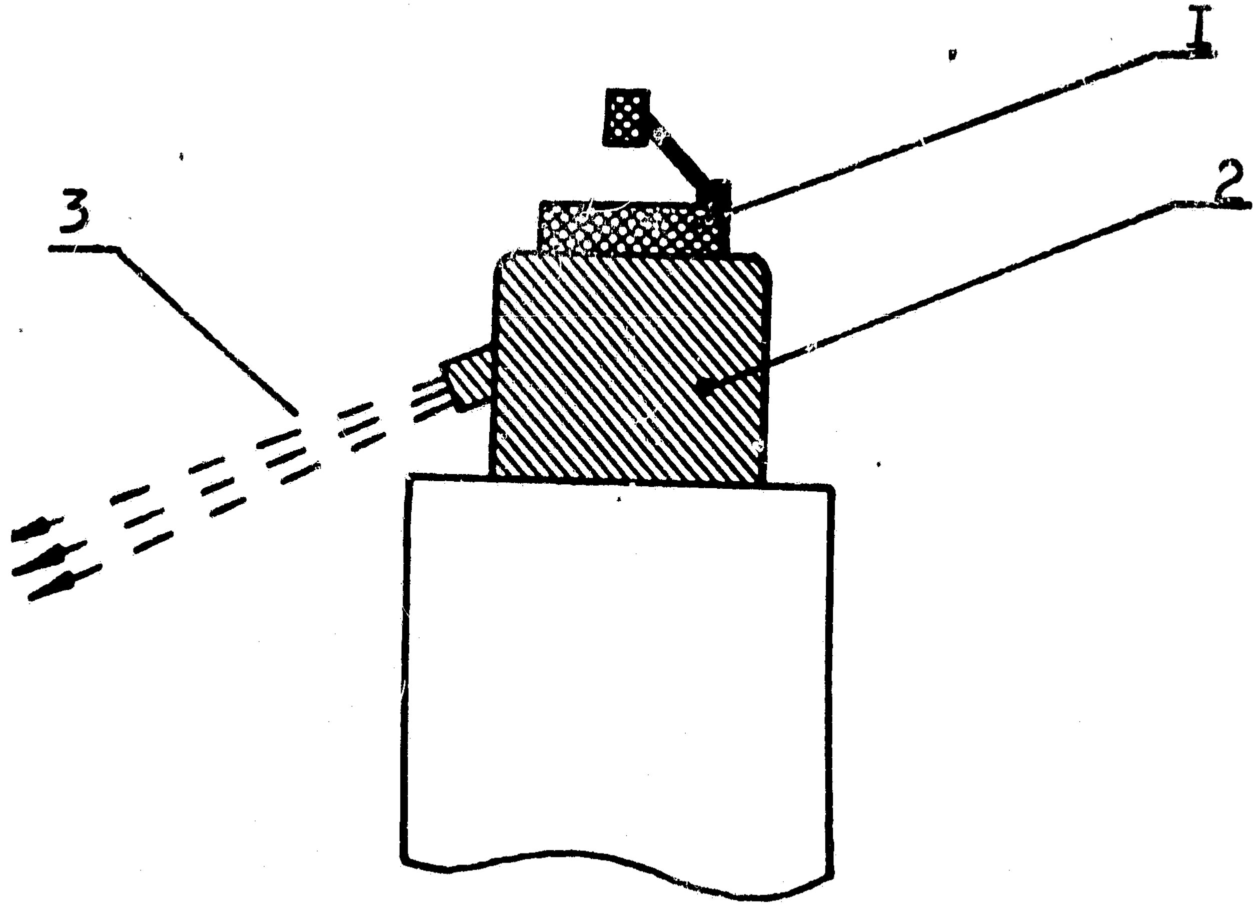

Fig. 2

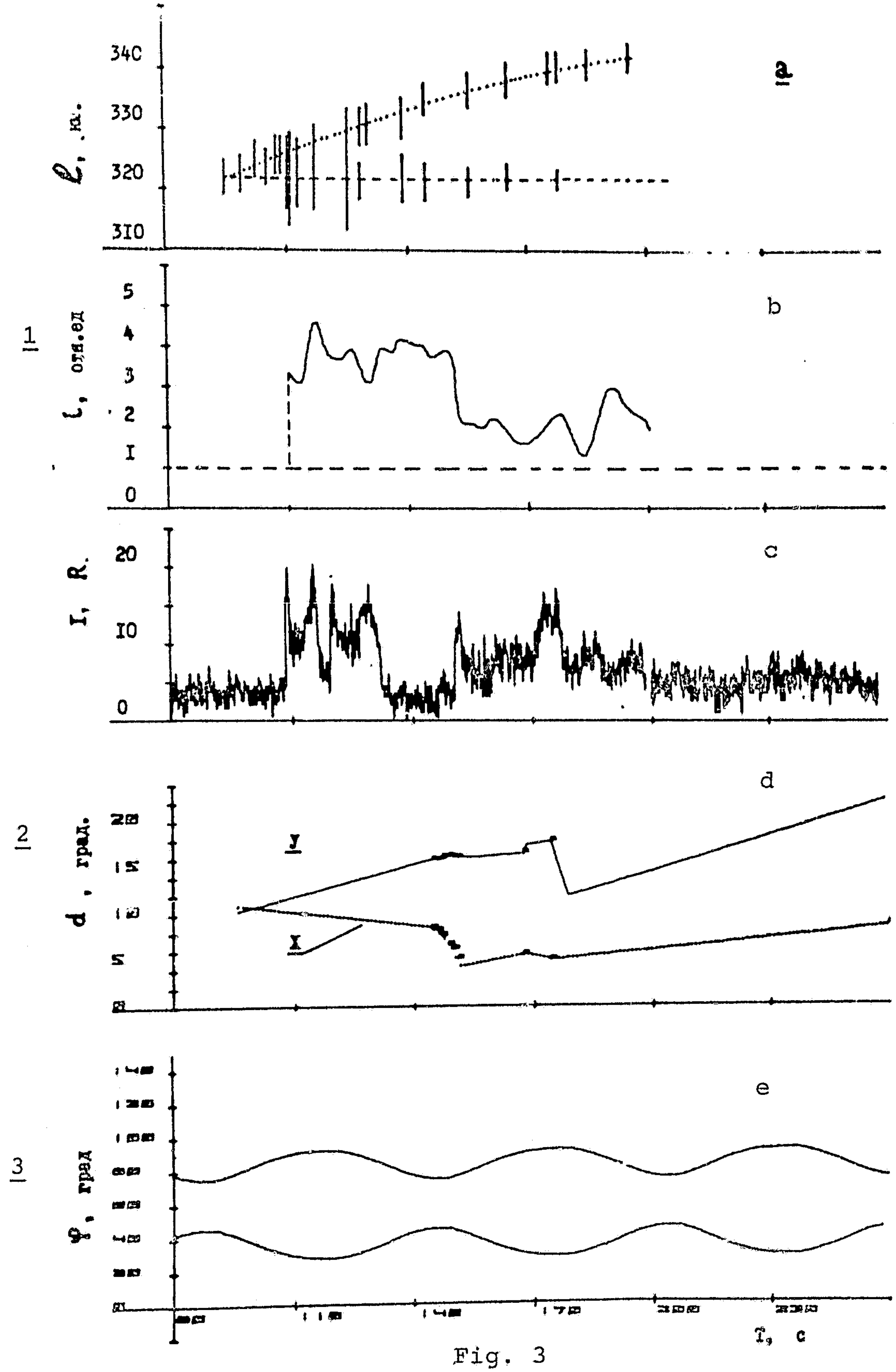

Fig. 3

Key: 1 - Relative units; 2,3 - Degrees.

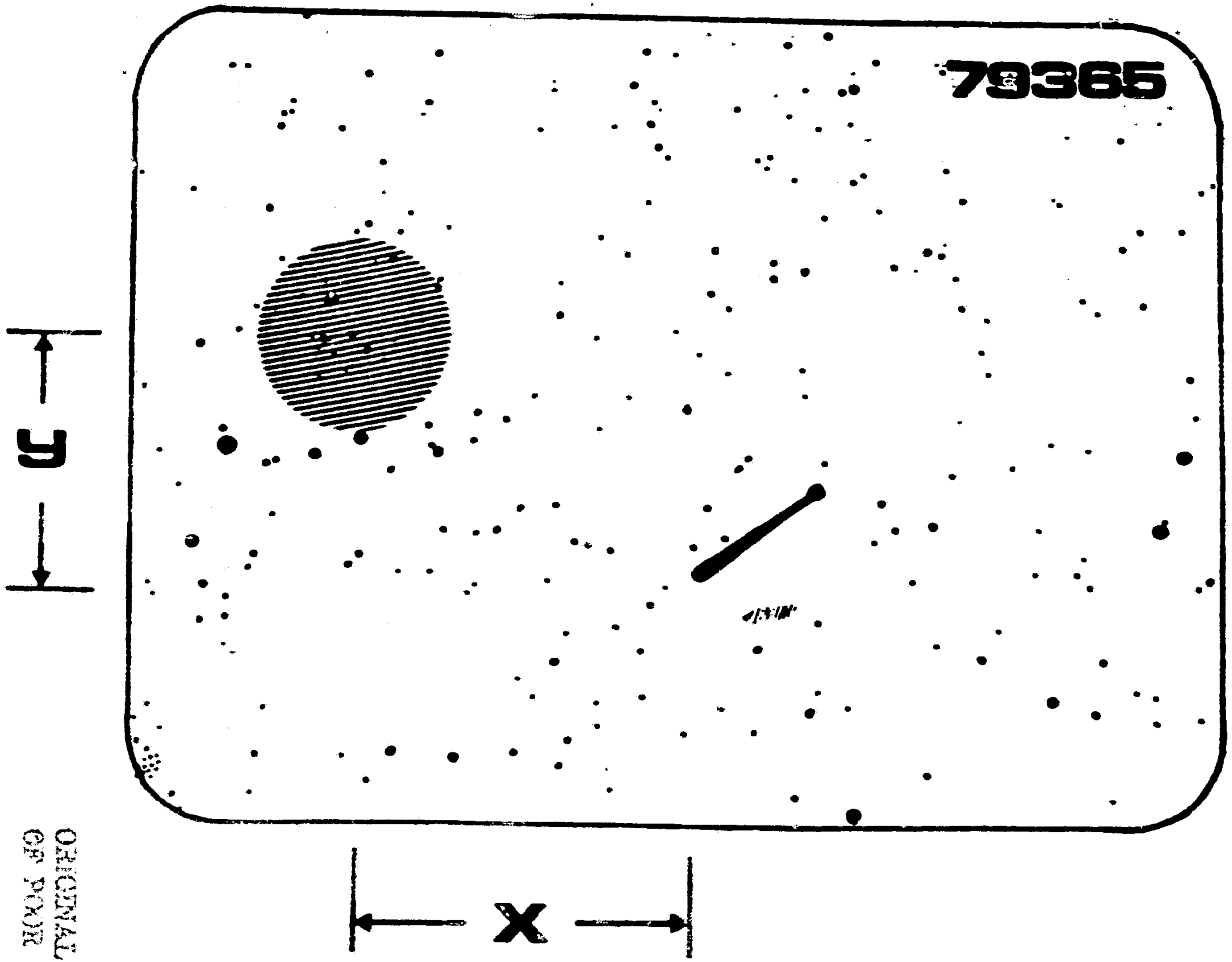

Fig. 4