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SOLAR OBSERVATIONS WITH THE LARGE PULKOVO RADIOTELESCOPE AT WAVELENGTH 3.2 cm.

V. IKHSANOVA.

The observations of the sun by means of the large Pulkovo radiotelescope [I] began in Desember 1956. In accordance with the antenna dimensions a fan-beam diagram about I' in width and I° in hight was expected (at $\lambda = 3.2$ cm).

The high resolving power of the instrument allowed to identify surely local radio sources with sunspot groups [2]. The daily records of the sun during December 23–29 th I956 are shown in fig.I. The projections of supots on a E–W line on December 23 d and 29 th are given in the same figure. Vertical lines mark the limits of the solar disk.

One can see that the half-widths of the local regions on the records coincide with those of the aerial diagram, thus the sise of the emitting region does not differ much from I'.

Taking these dimensions into account one can find the brightness temperature of the region. This appeared to depend on sunspot group parameters and to range between 0.3 ÷ I.0. [illegible]° Radioemission of these sources was rather steady for two or three months. It arose with the group, rapidly increased with the group growth and remained nearly constant as the group entered class F (Brunner – Waldmeier classification).

Sunspot group decay was followed by a decrease of radioemission. The radiation disappeared with the sunspots. In some cases the bright green line of the corona was observed in the region where the radio emission had been observed before.

In I957 and the beginning of I958 the motion of the emission regions connected with the sun's rotation was studied. Being situated at some height over the photospere radio emission regions were expected to move faster than the corresponding sunspots. Therefor comparing the distance of a sunspot from the central meridian with that of the emission region the height of the region can be determined.

Two examples of such determinations of height are shown on fig.2. The horisontal axis gives sunspot distances from the central meridian, the vertical axis - that of the radioemission region. Effective centers of emission appeared to be at the height I.07 $R_{\odot}$, that is in the lower corona.

Of special interest are the regions wich appear one day before the corresponding sunspots and also the regions which can be observed on the western limb of the sun one day after the disappearence of the group. In this way it is possible to predict the appearence of sunspot groups and to observe coronal condensations two days longer than the corresponding sunspot groups.

Thus our radiotelescope allows to take into account the radiation of the coronal condensations connected with sunspots behind the sun's limb. The correlation between sunspot area and solar radiation density was always uncertain owing to the absence of date about these unobserved sunspots behing the limb. In our case this uncertainty is overcome.

During July I6-30 I957 simultaneous observations of the sun at $\lambda = 10$ cm have been made with the same antenna by J.N. Parijsky. The distances of the local sources from the central meridian appeared to be the same at both wave lengths.

As the emission of local regions at $\lambda = 3.2$ cm is generated at the height I.07 R_o it can be supposed that these regions of microwave emission are located in the corona.

This assumption is in agreement with Waldmeier's hypothesis of coronal condensations over sunspots [ ].

Three components of the thermal solar radio emission are considered.

I. The quiet sun wich can be determined [illegible] No change in this level was found (at least during [illegible] months of observations). It is shown in fig. [illegible] [illegible] show the limits of the optical disk.

2. The second component is connected with [illegible] region in the chromosphere. It has an intensity [illegible] cent of the quiet sun and is of a rather [illegible] In some cases this component is [illegible] with [illegible]

3. The third component is connected with [illegible] in the lower corona.

It originates in local regions of [illegible] and is usually defined as a slowly - varing component. The flux from separate coronal condensation varies [illegible] ween 5 and [illegible] per cent of the quiet sun's level.

The auther is gratefull to Pref. S.E.Khaikin for advice in this werk.

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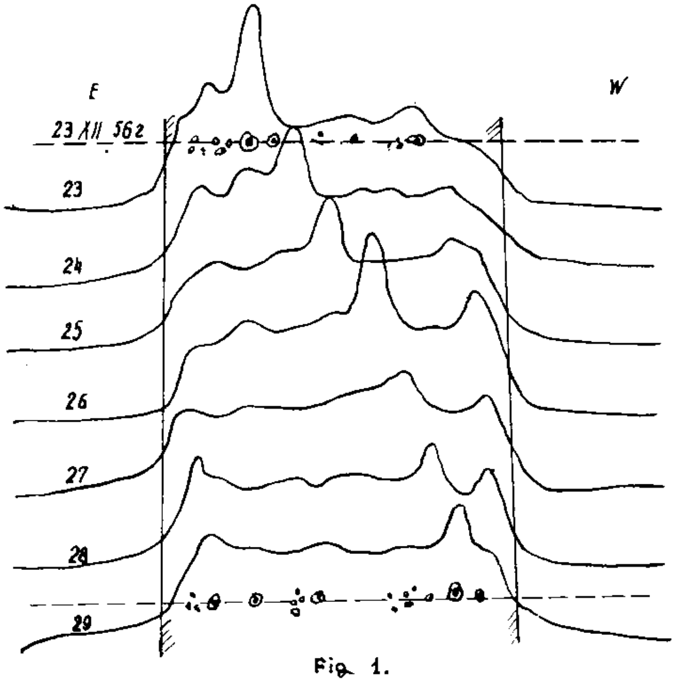

Fig. 1.

23-31 December 1956

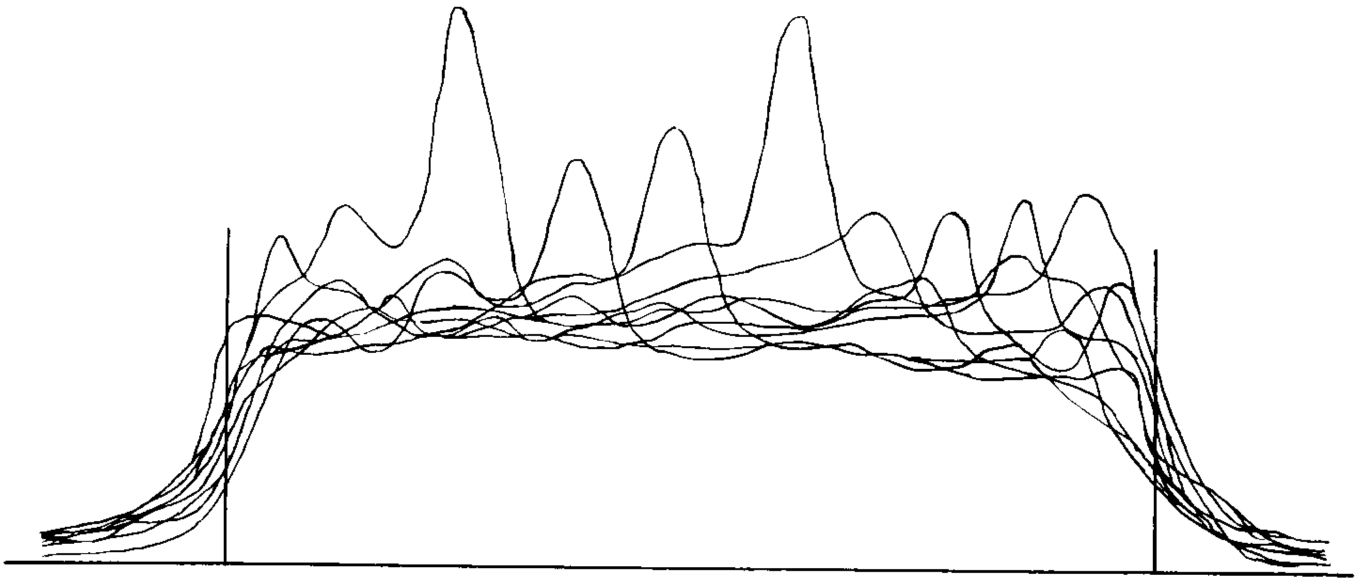

Fig.3

ON THE POLARISATION OF SOLAR RADIOEMISSION AT 1.5 m.WAVELENGTH

By U.J.Alekseev and Vitkevich, V.V.

1. Solar radioemission is usually characterized only by the intensity, i.e., by a single value at a given frequency. At polarized measurements the radio emission is characterized by four values (for example, by the unpolarized component intensity and three components of the polarization ellipse).

Here we see, that observations of solar radioemission with a polarimeter give us considerably more extensive information than the usual observations. It is very important that the character of polarization of the radioemission is determined by the value and direction of the magnetic field of emitting regions. Thus, we connect the polarized radioemission with a magnetic field, which is considerably higher than the field in the region, which we can study by optical methods.

It should be also noticed, that one of the most interesting and unsolved problems is the nature of the disturbed solar radioemission. It is clear that new information [illegible] the polatization of radioemission will contribute to the solution of this problem. In spite of the importance and urgency of the problem, investigations to solve it are [illegible] carried out only in a small number of observatories. The observations in Australia and the work carried out in [illegible] may be mentioned.

With the aim of carrying out this work at the [illegible] station of the Physical Institute of the [illegible] of the USSR the suitable apparatus was [illegible].

Two antennas mounted on one rotating arrangement [illegible] the signal. The first antenna consists of [illegible] horizontal dipoles with a reflector. The second [illegible] the vertical component consists of 20 [illegible] type and the same reflector. The receiver [illegible] type without modulation.

Simultaneously five different records are made: the vertical component of the signal, the horizontal component, three signals obtained as a result of composition with different phase displacements: left polarization ($\varphi = 90^\circ$), linear component inclined at 45° to the horizontal component ($\varphi = 0$), right polarization ($\varphi = -90^\circ$). The sensitivity of the receiver is 15°, the band is 150 Kc/s, the time constant is usually 0.5 sec. The band of the system is determined by the output of the intermediate frequency device. The total band of all the previous cascades is [illegible] Mc/s. [Observations of solar emission have been carried on from August 1957. They were carried on with an antenna following the Sun and with a sea radio interferometer. The antenna of the described radio telescope is situated on the Black See shore on the level of 284 meters, which corresponds to the width of one lobe of the reception pattern 8!8.

3. The first conclusion which can be drawn from the observations relates to the change of the degree of polarization of the radioemission of separate bursts (pips) in time.

For the determination of the degree of pips polarization during a day and from day to day, the ratio of signals on different channels of the polarimeter were calculated and plotted (fig. 2). On the curve the ratios are reduced so that the first corresponds to the equality of intensities of the signals affecting the channels. Such, degree of signal polarization does not depend on the total intensity of the signal, but is determined by the degree of polarization and the portion of the polarized part of the total signal intensity. Each point of the curve is obtained by averaging 8-10 pips during a period approximately of 10 minutes. Pips having only randomly polarized components (for these pips all rations are on the level of 1), which occur casionally, were not averaged.

On the basis of the study of polarization the following conclusions can be drawn:

a. The degree of polarization of pips usually does not change for a long period of time (for some days).

b. The polarization of pips is nearly circular (or in some cases random).

c. The degree of polarization of consequent pips is precisely not the same but is shows a dispersion exceeding the errors of the instrument and the calculation errors.

4. The sense of polarization usually changes rather quickly during less than 12 hours.

5. Observations with the sea interferometer enabled to measure the polarization of separate regions of increased radioemission (excluding the background of the solar radioemission) and the polarization of the pips. Fig.3 shows a comparison of polarization. It follows that the polarization of the regions of increased radio brightness is near to the polarization of the pips. This gives ground to conclude that the levels (the hight above the photospeare) of pips and the regions of increased radioemission are the same.

V.Vitkevich

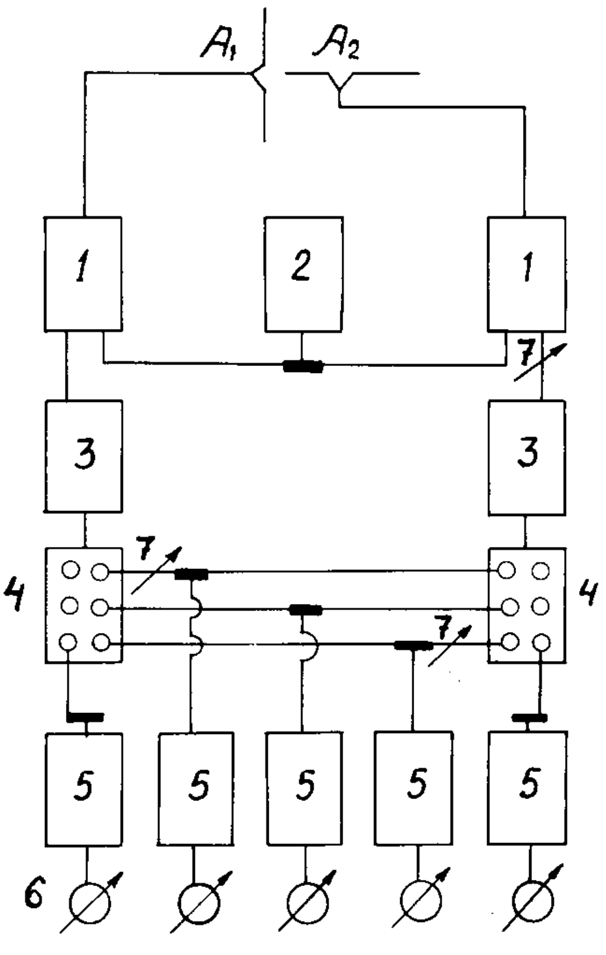

Fig. 1

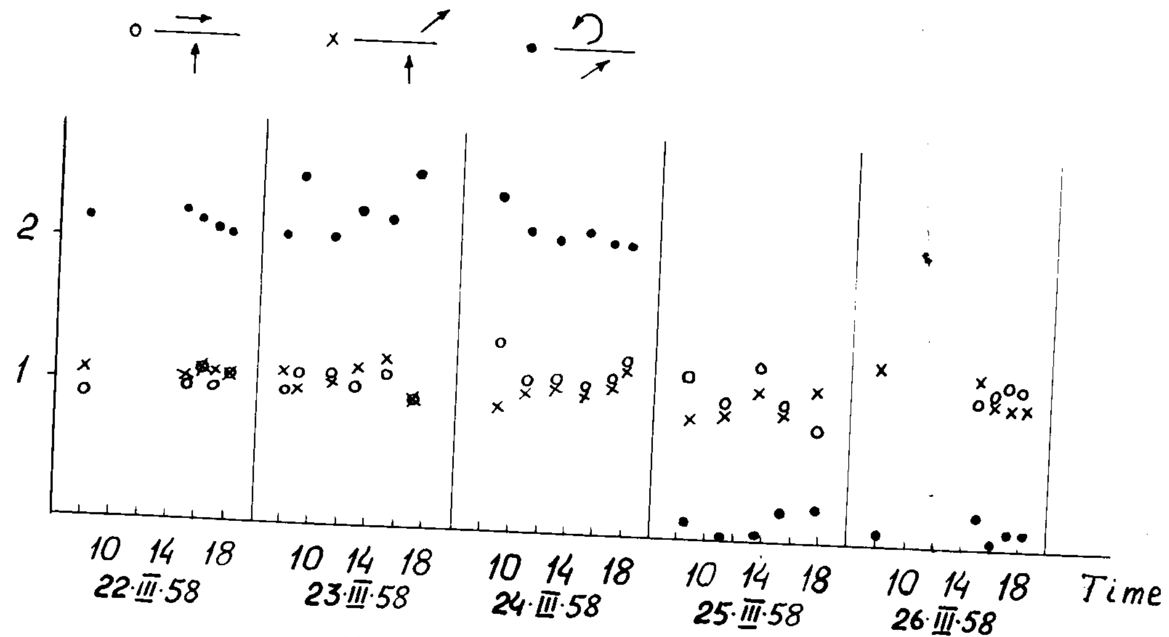

Fig 2.

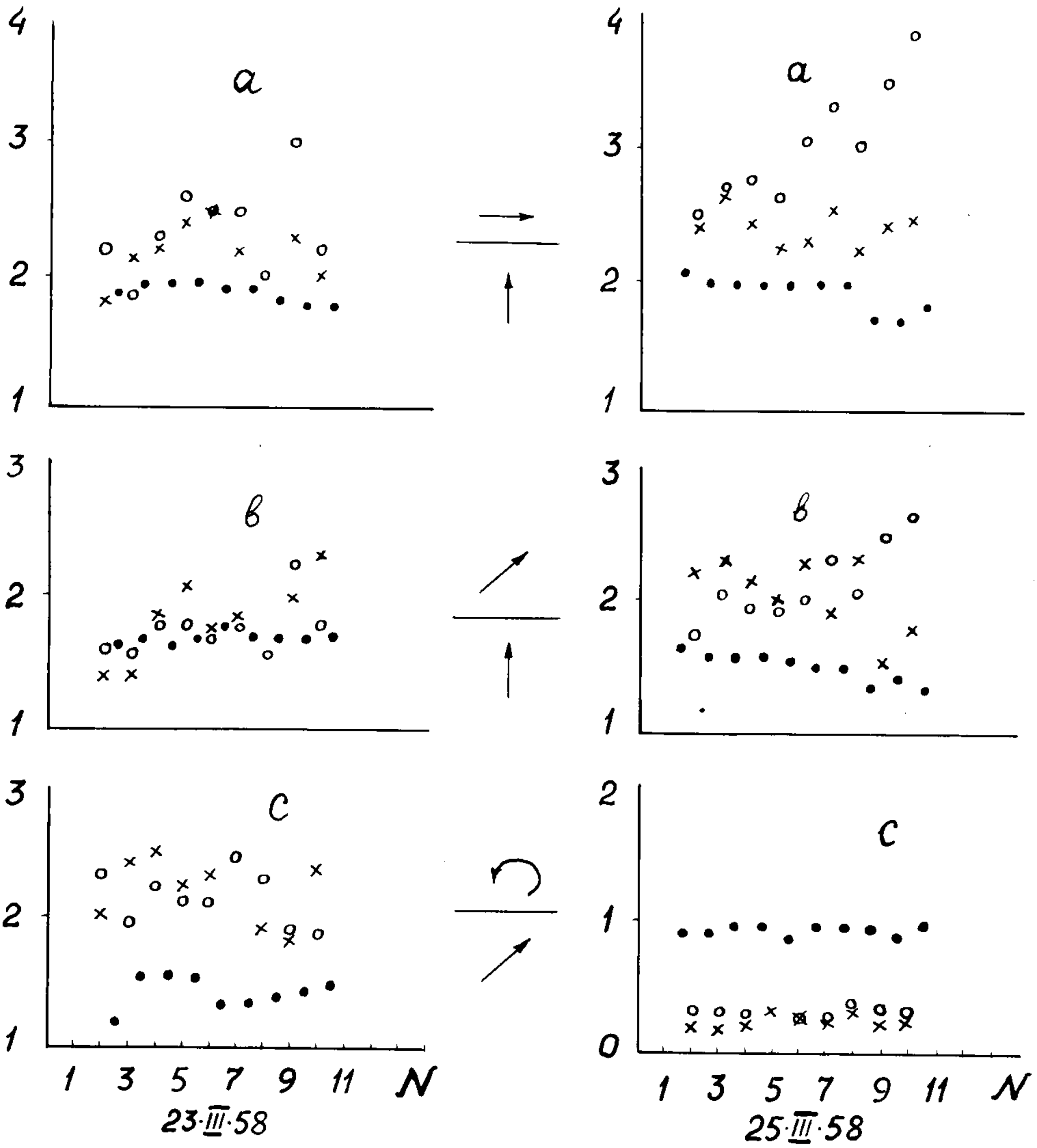

Fig. 3

A NEW RADIO TELESCOPE OF HIGH RESOLVING POWER

S.E.Khaikin and N.L.Kaidanovsky.

An attempt to construct large parabolic reflectors [illegible] has met with the following difficulties. For normal operation of radio telescopes it is necessary that no point of the reflecting surface deviates from the [illegible] by more than 0.1 λ. Therefore the larger the [illegible] radio telescope the higher are the requirements [illegible] relative accuracy (i.e. the ratio of the largest permissible deviation to the cross-section of the reflector). [illegible] has not been attained a relative accuracy higher [illegible] 1.10^{-4} in any of the existing radio telescopes and [illegible] grounds for supposing that it can be increased [illegible]

If the deviation from the theoretical form of the surface should not be more than 0.1 λ, then for a relative accuracy of 1.10^{-4}, the diameter of the reflector D cannot be much larger than 1000 λ. The limiting relative accuracy limits the resolving power of the reflector: the beam of the directivity pattern cannot be less than 3' (as [illegible] would be equal to about λ/D at half-power width).

For a future increase of the resolving power of radio telescopes it is necessary that new principles be applied which allow for the construction of reflectors of large size with a relative accuracy much higher than 1.10^{-4}. One such principles, which solves the above problem, was proposed by the authors in 1952 and has been realised at the [illegible] Observatory. The reflector consists of a large number of separate, not connected mechanically, reflecting elements which are adjusted so that together they form, with sufficient accuracy, the necessary reflecting surface. Therefore together with the increase in size of the reflector (by increasing the number of reflecting elements) the higher the requirements to the relative accuracy of the relative adjustment of the elements and not the separate elements themselves. The problem of adjusting the reflector is solved by geodetic methods, which as is known; permit an accuracy of the order of I.10^{-6} to be attained, i.e. much higher than that which can be realized in a reflector which is a mechanically whole construction. As the separate reflecting elements must be mounted on the ground; it is possible to considerably increase the size of the reflector in a horizontal direction. The directivity pattern of the radio telescope will have correspondigly a small beam angle only in the horizontal direction ("fan beam pattern"). However, as is shown in (I) and also according to the calculations by [illegible] Pariisky, the fan beam pattern for observations of one and the same objects at different azimuths gives a possibility in most cases to attain in both coordinates (right ascension and declination) a resolving power corresponding to a small beam angle. Therefore it is possible to accept the fact that the radio telescope gives a narrow directivity pattern only in the horizontal direction if observations can be made in any azimuth.

The necessary reflecting and focussing surface can be formed from the separate flat elements in the following manner.

Imagine a parboloid of revolution, the focus of which is fixed at a certain height above the Earth's surface. For observations in defferent directions this "initial paraboloid" must turn about the focus so that its axis coincides with the necessary direction. (fig.I). The intersection of the paraboleid with the horizontal surface MN, which passes through the focus, is an ellipse (fig.2) defined by the equation

$$\rho = \frac{p}{1 + \cos\alpha \cdot \cos\varphi}$$

where ρ is the distance of a point on the ellipse to the focus, p – the parameter of the initial paraboloid, α – the altitude of the celestial body.

If the flat reflecting elements are placed close to one another along this ellipse, tangent to the paraboloid at points of the ellipse, then by selecting the corresponding size of these elements, the reflecting surface will transform the plane wave incoming the axis of the initial paraboloid into a converging cylindrical wave which has a vertical focal line, passing through the focus of the initial paraboloid. For this it is necessary that the width of the element l be so small ($l < \sqrt{\tfrac{1}{2} p \lambda_{min}}$) that the path-difference from the edge of the element to the focus be small in comparison to the length of the shortest wave used, the height h so large ($h > \sqrt{2p\lambda_{max}} \cdot \frac{1}{\cos\frac{\alpha}{2}}$) that the diffraction of the longest wave used be negligible at its propagation between the reflecting elements and the focus. Then the rays reflected from all the points of the element which lie in the plane MN, will come to the focus of the initial paraboloid.

in the one and the same phase. The rays reflected from points of the element, which lie in the same vertical plane, will come in the same phase to points at the respective heights on the vertical line passing through the focus (fig.I). This means that the surface formed by the reflecting elements will transform the plane wave into a cylindrical wave spread in a horizontal direction and converging at a focal line, passing through the focus of the paraboloid. By placing near the focus a second reflector in the form of a parabolic cylinder, with a horizontal generatrix and a focus situated symetrically to the focus of the main reflector, it is possible to transform the converging cylindrical wave into a spherical wave converging in the phase center of a feed of any type.

As the many-sided reflector has periodic errors and slits between the separate reflecting elements this leads to the appearance of far and weak diffracting lobes and therefore to the decrease (by several percents) of the area efficiency coefficient but does not influence the form of the major lobe.

As the focus of the initial paraboloid is always in one horizontal plane (near the Earth's surface) for all angles of observation, it is necessary when adjusting the feed in a given direction that it moved only in a horizontal plane and rotated about the vertical axis.

The reflecting surface of the antenna is given the necessary form by a translational movement of the reflecting elements and also their rotation about the horizontal and vertical axes.

The translational movements can be reproduced with sufficient accuracy by moving the reflecting element [illegible] along the radius of the circle on which [illegible] these elements should be fixed, when observing in the zenith. The relative movement of the reflecting element in the radial direction is given by:

$$\delta = \frac{\Delta R}{R} = \frac{\cos\Omega(\sin^2\alpha - q) - \sqrt{\cos^2\Omega(\sin^2\alpha - q)^2 + (2q - \sin^2\alpha)(1 - \cos^2\alpha\ [illegible])}}{1 - \cos^2\alpha \cdot \cos^2\Omega}$$

[illegible] Ω is the angle of [illegible] reflecting element [illegible] from the center of the [illegible] (fig. 2), $q = \frac{\rho}{R}$.

From the point of view of constructi[illegible] it is very essential that the movement in the radial direction be small. This is accomplished by selecting for each angle α the most suitable parameter p of the [illegible] [illegible], for the curve of the middle line of the [illegible] surface differs minimally from a circle of radius [illegible].

The angle of inclination β of the reflecting [illegible] seen from the focus under the angle φ can be [illegible] from:

$$\sin\beta = \frac{\sin\alpha}{\sqrt{2(1 + \cos\varphi \cos\alpha)}}$$

The reflecting elements need to be rotated about the vertical axis through the angle $\Omega - \psi$; where ψ is determined by

$$tg\,\psi = \frac{(1-\delta)\sin\Omega}{\sqrt{q^2 - (1+\delta)^2 \sin^2\Omega \sin^2\alpha}}$$

The mounting reflecting elements along the whole circumference gives a possibility of observing in all azimuths. If there are automatic operating devices a rapid adjustment of all the elements of the reflector for observations in the necessary direction may be made and the scheduled program of following the source observed. The above principle has been partly realised in the large radio telescope at the Pulkovo Observatory (fig.3). At present the radio telescope has 90 reflecting elements of dimensions $l = 1.5$ m, $h = 3$ m, placed along an arc $2\Omega_m \approx 90°$ of the circle with a radius $R = 100$ m. Each of the reflecting elements has a device which permits a movement in the radial direction of 30 cm and also a rotation on the horizontal and vertical axes. The reflecting elements are adjusted by hand according to the scales attached to the mechanisms and spirit levels.

The completed radio telescope at wavelength 3,2 cm. has a fan-beam diagram $1'$ in width and from $10'$ to $1°$ in height (depending on the altitude of the direction of observation).

The principle proposed allows to construct a microwave radio telescope with an area of about twenty thousand square meters. This principle can also be used with success at longer wavelengths. It possible to construct a radio telescope of area 100 000 m^2 for a range of wavelengths from 20 cm. to 2 m.

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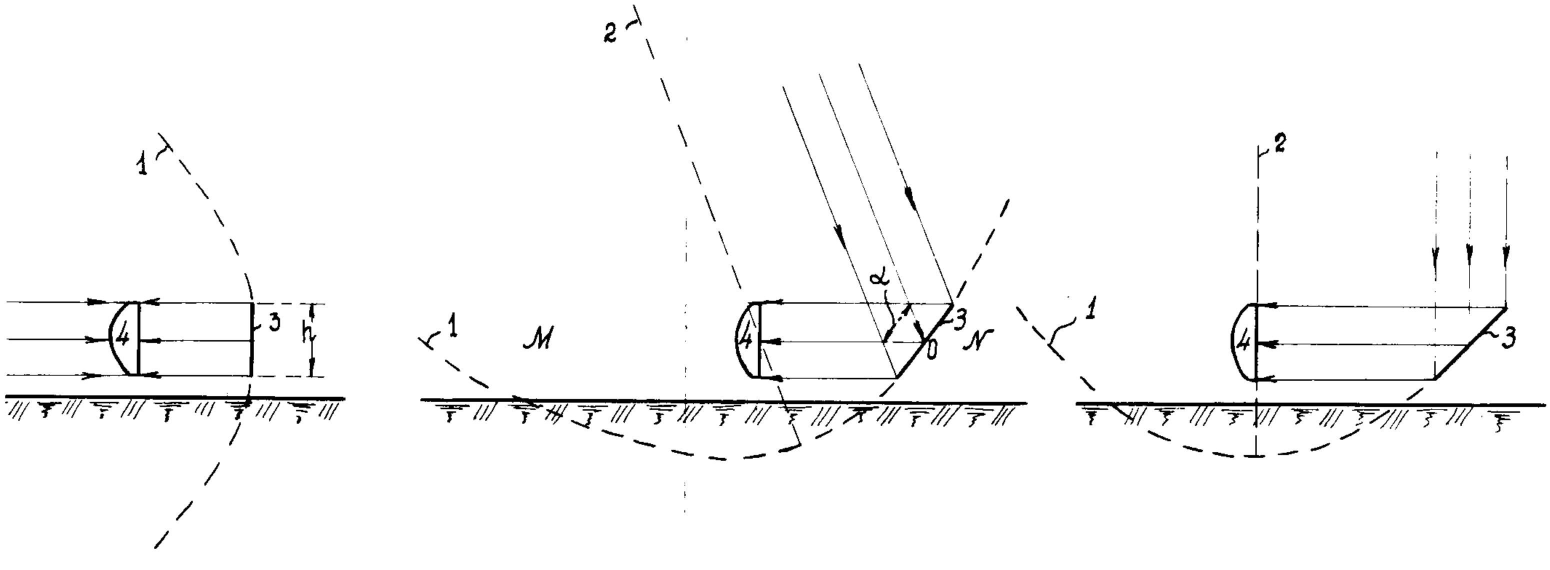

1. Imaginary paraboloid of revolution.
2. The axis of the paraboloid directed to the celestial body.
3. The reflecting surface.
4. Feed.

α. The altitude of the celestial body.

Fig. 1

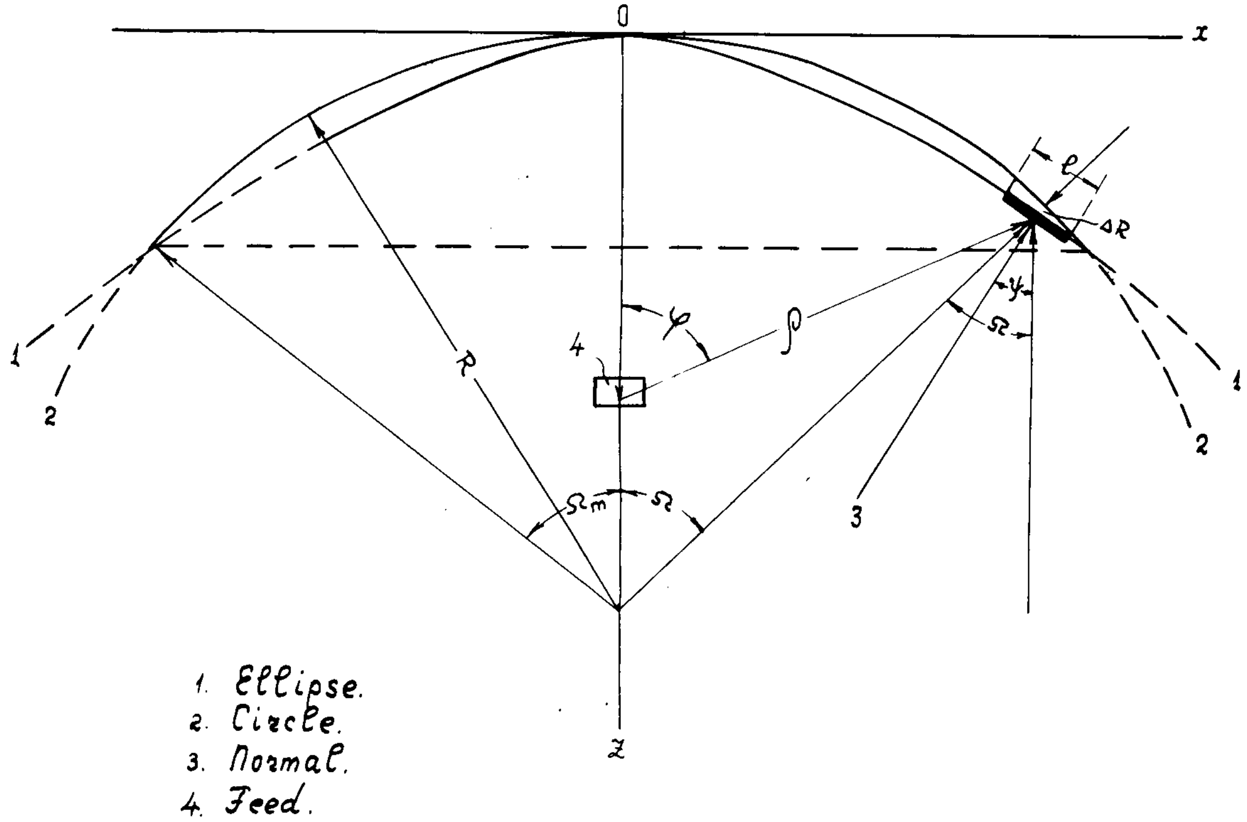

Fig. 2

ON THE MECHANISMS OF SPORADIC SOLAR RADIOEMISSION

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The mechanism of generation of a sporadic(non-thermal) solar radioemission,which is of a great interest for radioastronomy and solar physics, is rather obscure. Recently,the authors considered this problem in the papers[1-2]. This report gives their summary.

Comparing the mechanisms of radioemission,it is convenient to divide them, on the one hand,into incoherent and coherent ones,and,on the other, into the mechanisms related to the isotropic plasma and magnetoactive plasma respectively. In addition, it is convenient to consider preliminarily the conditions of propagation and output of electromagnetic waves from the solar corona.

1. Propagation and Output of Electromagnetic waves from the Corona.

Transversal waves 1 and 2 and a longitudinal plasma wave 3 can propagate in the isotropic plasma. Squares of the refraction indexes for these waves are equal respectively to

$$n_{1,2}^2 \simeq \varepsilon \simeq 1-\frac{\omega_0^2}{\omega^2} \equiv 1-\frac{4\pi e^2 N}{m\omega^2} \,,$$

$$n_3^2 = \frac{\varepsilon}{\beta_T^2} \simeq \frac{1-\omega_0^2\,\omega^2}{V_T^2/c^2} \,, \qquad (1)$$

where N-electron concentration, $v_T=\sqrt{\frac{\varkappa T}{m}}$,T-kinetic temperature and e,m,c,$\varkappa$ -charge and mass of the electron, light velocity and Boltzmann constant.

In the regions of the corona where $\varepsilon>0$, the waves 1 and 2 are slightly absorbed due to collisions (the role of these collisions is neglected in /1/). The damping of the wave 3 takes place ,even if the collisions can be neglected, this damping becomes weak only when $\lambda=\frac{c}{\omega n_3}$ exceeds Debay's radius $D=\sqrt{\varkappa T/4\pi e^2 N}$.

In the isotropic coronal plasma electron streams generate only plasma waves, we however are interested in transversal waves outgoing from the corona. In a homogeneous plasma, transformation of plasma waves into transversal ones (e.g.radio-waves)takes place only due to scattering on fluctuation of the electron concentration $\delta N=\delta N'+\delta N''$.

Here $\delta N'$-fluctuations of N ~~[illegible]~~ due to variations of the plasma density, and $\delta N''$-fluctuations of N when ion density does not vary practically. Scattering on fluctuations of $\delta N'$ is not followed by a considerable change of frequency(Reyleigh scattering), so the radio wave formed as the result of scattering has the frequency of a scattering plasma wave. Fluctuations $\delta N''$ are a combination of plasma waves of a fluctuation origin. Radio waves produced due to the plasma wave scattering on $\delta N''$ fluctuations have the frequency $\omega\sim 2\omega_0$,since the frequency of slightly damping plasma waves is close to ω_0 .

The whole energy flux of radio waves formed at

Rayleigh scattering of the plasma wave on thermal fluctuations of $\delta N'$ in the volume $V \sim L^3$, is equal to

$$P'(\omega) = \frac{n_{1,2}(\omega) e^4 N V}{6 m^2 c^3} E_0^2, \qquad (2)$$

where E_0 -electric field amplitude in the plasma wave. The transformation coefficient for the incoherent plasma waves

$$Q' \equiv \frac{P'}{S L^2} \sim \frac{4\pi e^4 N L}{3 m^2 c^3 V_T}, \qquad (3)$$

where $S \simeq \frac{E_0^2}{8\pi} \frac{d\omega}{dk} = \frac{E_0^2}{8\pi} \cdot \frac{k V_T^2}{\omega}$ — energy flux in the plasma wave. At $N \sim 10^8 \text{cm}^{-3}$, $L \sim 10^9 \text{cm}$, and $T \sim 10^6 K$ $(V_T \sim 4.10^8 \text{cm.sec}^{-1})$ one obtains $Q' \sim 3.10^{-6}$. For the scattering on $\delta N''$ fluctuations, the value of the coefficient of transformation $Q'' \lessapprox Q'$ if there are absent the scattering plasma waves of a nonthermal origin.

In an inhomogeneous isotropic plasma, besides transformation due to scattering, there can take place a regular transition of plasma waves into radio waves in the regions where $\omega_0 = \left(\frac{4\pi e^2 N}{m}\right)^{1/2} \sim \omega$; at the same time the plasma waves must fall at small, but not zero, angles towards the gradient N (see /4,5/). For the plasma waves with a wide angular spectrum, the corresponding coefficient of transformation $Q \lessapprox 10^{-6}$.

When influence of a magnetic field is taken into account (plasma being magnetoactive), extraordinary and ordinary waves 1 and 2 propagate in the plasma.

The values of n_1^2 and n_2^2 for those waves (they are calculated by the well-known formulae (see, for example, [6-8]) are given for the corona in Fig.1 and Fig.2a for different values of the magnetic field and at the angle $\alpha = 15^\circ$ between the directions of the field $\vec{H_0}$ and wave vector $\vec{k}$ (the case $\alpha = 0$ is exceptional, and we do not consider it for simplicity; $\alpha \neq 0$, Fig.1 and Fig.2a give a qualitative information of the behavior of $n^2_{1,2}$ in the corona, when the values of N and H_0 decrease with increase of the height above the photosphere). Fig.2b gives $n^2_{1,2}$ and n^2_3 for the same dependence N(R/R$_0$) as in Fig.1 and Fig.2a but for zero magnetic field; thermal motion is neglected in the Figs 1-2a, it is taken into account in [8,9]; in the case of Fig.2b, the formulae [illegible] were used). It is important that in Fig.2a a crossed branch of the curve in a sufficiently weak field corresponds by all properties, to a crossed branch of the curve n_3^2 in Fig.2b.

If electromagnetic waves are generated in the region of the corona where $n^2_{1,2} > 1$ (see Figs 1,2a), the problem of the emission output from the magnetoactive coronal plasma is reduced to determination of the coefficient of transformation of the wave with $n^2_{1,2} > 1$ into the waves 1 and 2 capable to propagate at large values of R/R$_0$. In the homogeneous magnetoactive plasma, the output is possible only as a result of scattering, and it takes place approximately in the same way as in the isotropic medium. At the same time, in the inhomogeneous plasma, there is possible a regular transition of one normal waves into the other in the regions which are outlined in Figs 1,2a. This transition is especially effective at small angles α, and, besides, depends on strength of the magnetic field

H_0 (see /8,10/). Generally speaking, in the fields $H_0 >$ [illegible] oersted, the output of radiation due to scattering plays the main role.

2. Radiation in Isotropic Plasma.

Outbursts of the IInd and IIIrd types forming a considerable part of the sporadic solar radioemission, are unpolarized or, in any case, nearly unpolarized. Taking into account the conditions of radiowaves propagation and output from the corona, one comes to a conclusion that the magnetic field in the region of generation of the outbursts of the IInd and IIIrd types is weak; according to some estimates there $H_0 < 1$ oersted. Under such conditions the plasma in the first approximation can be considered as isotropic.

Frequency drift and some other peculiarities of the outbursts of the IInd and IIIrd type permit to conclude that they are generated by particle streams. In the isotropic plasma these streams excite the longitudinal waves only. In the case of the incoherent emission the last fact is clear, because the condition of existence of the Vavilov-Cherenkov effect has the form $\beta n_i \equiv \frac{v_0}{c} n_i > 1$ and is fulfilled for the wave 3 only, since $n_{1,2}^2 < 1$. Existence of a longitudinal electric field in the plasma wave leads to instability of the stream in the plasma resulting in a coherent emission of the plasma waves. Let's note that from the quantum point of view instability of the stream in plasma is connected with the fact that this system has a negative absorption (i.e. induced emission of plasma waves prevails over their absorption). Incoherent and coherent emissions of plasma waves arise simultaneously, but they differ by their dependence on the corresponding parameters and also differ by their frequency and angular spectra.

Energy of incoherent plasma waves emitted per sec. by the stream in the frequency range $d\omega$ is equal to

$$P(\omega)\,d\omega \sim N_s L^3 \frac{4e^2\omega_0}{3v_0} \ln\left(1+\frac{3}{2}\frac{v_0^2}{v_T^2}\right) d\omega \qquad (4)$$

where N_s -particle concentration in the stream, V_0 -their velocity and L^3 - volume of the stream. Hence one can conclude that an effective temperature of the emitting region with the area of the order of L^2, is equal to

$$T_{eff}(\omega) \sim \frac{2\pi^2 c^2}{\omega^2 \varkappa L^2} e^{-\tau} Q \frac{\Delta\Omega^*}{\Delta\Omega} P_\omega^* \qquad (5)$$

Here $\Delta\Omega^*$ and $\Delta\Omega$ -solid angles for emission of plasma and radio waves respectively, Q -transformation coefficient, and τ-optical thickness for radio waves. Assuming

$Q \sim 3\cdot10^{-6}$, $\Delta\Omega^* \sim \Delta\Omega \sim 1$, $\tau \sim 1$; $V_0 \sim 5\cdot10^9$ cm.sec^{-1};
$L \sim 10^9$ cm, $\omega \sim \omega_0 \sim 2\pi\,10^8$ sec^{-1}

we obtain $T_{eff}(\omega) \sim 7\cdot10^{1} N_s$

for the permissible concentration $N_s \sim 3.10^7$ we have

$$T_{eff}(\omega) \sim 10^9 \,{}^\circ K$$

This value determines the upper limit of T_{eff} since reabsorption of plasma waves in the corona is not taken into account.

[illegible] be rather essential. Unfortunately, we could [illegible] account the reabsorption entirely and it [illegible] only to indicate the lower limit of $I_{eff}\,\min$ [illegible] stream $I_{eff}\,\min \sim 5\cdot10^{40}\,K$, for the [illegible] ized quasineutral stream the value of $I_{eff}\,\min$ [illegible]

Thus it follows from the estimates given above [illegible] the incoherent emission of plasma waves by streams [illegible][x], in the main, appearance of the outbursts of the IIIrd type, however, it is quite possible that further [illegible] of the reabsorption will change the situation [illegible]

At the same time the outbursts of the IInd type cannot be identified with the incoherent emission, since the velocity of these particles $V_0 \sim 10^8\ \text{cm}\cdot\text{sec}^{-1} < V_T \sim 4\cdot10^8\ \text{cm sec}^{-1}$ (V_T corresponds to the corona temperature $T \sim 10^{6\,\circ}K$). The point is that in the case when $V_0 < V_t$, a charged particle does not generate the Cherenkov radiation.

The coherent emission of plasma waves by corpuscular streams is able to explain the peculiarities of the outbursts of the IIIrd type, and in all probability, of the outbursts of the IInd type.

Under certain assumptions (assuming $V_0 \gg V_T$ and $\Omega_s \ll \omega$), the amplitude of the stationary plasma wave $E_0 \sim 2\cdot w^{6}$ [illegible] if

$$\omega \sim \omega_0 \sim 2\pi\cdot10^{8}\ \text{sec}^{-1},\ [illegible] \sim 5\cdot w^{9}\ \text{cm}\cdot\text{sec}^{-1},\ T_e \sim T \sim 10^{6}\ {}^\circ K$$

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[x] Let's note also that in the case of the incoherent radiation appearance of overtone with the frequency of $2\,\omega$ can be connected with the scattering on fluctuations [illegible]

where T_s and T -temperature in the stream and corona, respectively). Hence for the effective temperature of the waves, one obtains

$$T_{eff}(\omega) \sim \frac{4\pi^3 e^2}{\omega^2 æ L} \frac{e^{-\tau}}{\Delta\omega \dot{b} \Omega} P'(\omega) \sim 10^{-5} P'(\omega) \sim 10^{26} N_s^{4}/N^{8} \qquad (6).$$

where $P'(\omega)$ is determined by the formula (2) with $n_{1,2}(\omega) \sim$ [illegible] In (6) it is put also $L \sim 10^9$ cm, $N \sim 10^8$ el.cm^{-3}, $\tau \sim 1$, $\Omega \sim 0$, and assumed that width of the spectral band [illegible] $\Delta\omega \sim 0,1\omega \sim 2\pi . 10^7$ sec.$^{-1}$. Thus, at $N_s \sim 2\cdot\omega^{-2} N \sim 2\cdot\omega^6$ cm^{-3} $T_{eff} \sim 300^{12}$ °K, what corresponds to the value $T_{eff\odot} \sim 10^9$ °K related to the whole solar disk. The last [illegible] is sufficient for explanation of the outbursts of the I-st type.

Let's note that for the outbursts of the IInd type a new quantative calculation must be done since in this case the particle velocity in the stream $V_0 < V_t$. However, we think that the coherent radiation is able to explain peculiarities of the outbursts of the IInd type also. Appearance of overtone in the outburst spectrum is easily explained by non-linear character of oscillations in the stationary plasma wave. It is not excluded, however, that overtone can be connected with the output conditions and depends on plasma wave scattering.

3. Radiation in Magnetoactive Plasma.

Since the outbursts of the Ist type and high-level radiation above the spots are polarized, generation of [illegible] components must be considered taking into account influence of the magnetic field. In this case the incoherent emission of moving particles can be divided into the Vavilov-Cherenkov radiation and magnetobremsstrahlung (synchrotron) radiation connected with rotation of fast electrons around the lines of force with the frequency $\omega^* = \omega_H\sqrt{1-\beta^2} = \frac{eH_0}{mc}\frac{mc^2}{E}$ magnetobremsstrahlung radiation is generated both in the region $n_i > 1$ and in the corona layers where $n_i < 1$. Therefore as one can see from Figs 1-2 the problem of output of [illegible] radiation from the corona is not difficult.

High-level radiation above the spots can be of magneto-bremsstrahlung origin/5,11,12/. In order to explain the observed level of radiation, it is sufficient to suppose that in the magnetic field above the spots we have electrons with the energy $E \lesssim 10^6$ ev and concentration $N \sim 1$ el.cm^{-3}. [illegible] mechanism of electron acceleration up to the energies $E \sim$ [illegible] is briefly discussed in /5/. At the same time the problem of the magneto-bremsstrahlung mechanism is not sufficiently clear yet, since the model taken in /12/ needs modification (see /5/). Due to this reason it is difficult to say whether it is possible to provide on the basis of the magneto-bremsstrahlung mechanism, predominance of the ordinary component in the high-level radiation.

At the same time it is impossible to explain the bursts of the 1st type by the magneto-bremsstrahlung radiation of electrons, since there is no reason to assume that emitting particles can considerably change their energy for the time $\lesssim 1$ sec. characteristic for the outbursts of the Ist type. The outbursts of the IInd and IIIrd type can not be connected with the magneto-bremsstrahlung radiation (in any case, if one assumes electrons to be weakly relativistic what is necessary for explanation of overtones [illegible] where the magneto-bremsstrahlung mechanism of the outgoing radiation is proposed, the reabsorption radically changing the conclusions (see /5/ was not taken into account.

The effect of Vavilov-Cherenkov is possible only in those regions where $\beta n_{1,2} > 1$. It is clear from Figs. 1 and 2 that output of this radiation is complicated and, in all probability, the coefficient of transformation Q do not exceed the above-mentioned values for the isotropic plasma. In addition, excluding the case of weak fields $H_0 < 1$ oersted, mainly the ordinary wave will go out. It is impossible also to explain the outbursts of the Ist type on the basis of this mechanism(the reason is the same as in the case of the magneto-bremsstrahlung radiation). Thus, The Vavilov-Cherenkov effect in the fields $H_0 > 1$ oersted can, in the main, lead to high-level radiation only, but also in this case its role can be considerably less than that for the magneto-bremsstrahlung radiation[x].

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[x] Power of the magneto-bremsstrahlung radiation and Cherenkov radiation under the considered conditions is, roughly speaking, of the same order. Therefore, the role of the Cherenkov radiation is depressed due to a small efficiency of its output. It is possible, however, that this efficiency considerably increases due to the scattering of the considered Cherenkov waves on the other non-equilibrium waves of the same origin.

In a weak field the Vavilov-Cherenkov affect is ,as a matter of fact, equivalent to radiation of plasma waves in the isotropic plasma(see section 1 and Figs 2a,2b. The connection of incoherent plasma waves with the outbursts of IInd and IIIrd types has been already considered above.[x]

The stream of charged particles moving in the magnetoactive plasma is generally speaking, unstable that leads to the coherent radiation of ordinary and extraordinary waves. The point is that at $\alpha \neq 0$ a longitudinal electric field exists in these waves. This field causes grouping of radiating particles (as in the case of longitudinal waves in the isotropic plasma). If the magnetic field is weak (roughly speaking $M_o < 1$ oersted), this coherent radiation is practically identical to the coherent radiation of plasma waves considered in Sector 2 when it was applied to the outbursts of the IInd and IIIrd type. In stronger fields the coherent radiation goes out from the corona mainly in the form of the ordinary waves therefore it can be only connected with high-level radiation and also with the outbursts of the Ist type. In the last case we mean excitation of free oscillations of the coronal plasma, during the time of their damping, generation of the outbursts of the Ist type takes place.

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[x] In the paper /15/ at the discussion of the Cherenkov radiation reabsorption was not taken into account in the corona, and the output conditions were ignored. Let's note in addition that an attempt/15/ to connect radiation on the frequ-

Estimates show that in order to produce the observed flux of radiation of the outbursts of the Ist type, we must have free plasma oscillations in the corona with the amplitude $E \leq 10^{-1}$ CGSE units. The excitation mechanism of such oscillations is, however, obscure (perhaps, shock magneto-hydrodynamical waves play the role of an exciting agent)[x]

Let's note that in the paper/16/ /see [illegible] mechanism of free oscillations of the ionospherical plasma is put forward in order to explain short sporadic outbursts of the Ist type emitted by the Jupiter and Venus.

In paper /14/ it was assumed that the outbursts of the Ist type are due to the magneto-bremsstrahlung radiation of the system of electron packets (a size of every packet $\ell < \lambda$). Electrons of every such packet give the coherent radiation, but a total radiation of the whole system consists of the radiations of separate packets(i.e. the electron phases in different packets have [illegible] a random distribution). It is clear, however, that such conditions cannot take place in the solar corona, where a length free path ℓ_{fr} exceeds by 4-6 orders the wave length of the sporadic radiation in the corona $\lambda \sim 10^2 - 10^4$ cm. Indeed, appearance of packets with $\ell \leq 10^2 - 10^4$ cm in the plasma with $l_{free} \sim 10^8$ cm, and, also,

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encies ω and 2ω with the frequencies ω_0 and ω_H seems to be [illegible] artificial.

[x] The attempt made in /17/ to explain excitation of plasma waves by instability of the shock wave front is groundless(see [illegible]).

existence of definite phase relations which provides coherency in the region with a characteristic size of ℓ seems to be doubtful. Moreover, if the packets were produced, they would essentially change their form during the time of the order of $10^{-7} - 10^{-5}$ sec.(this time is sufficient for electrons with a velocity $v_T \sim 4.10^8$ cm.sec^{-1} to pass along the magnetic field a distance of the order of λ). Let's note also, that increase of radiation intensity of every packet due to coherency is compensated by the corresponding increase of its absorption. Therefore the resulting radiation in a sufficiently thick layer will be the same, as for the system of incoherent electrons.

Summing up, we can say that general points of the theory of the sporadic solar radioemission seem to be already clear. At the same time, a number of important questions and details must be considered. For a further development of the theory, it is necessary in the first place: to determine polarésation of the magnetobremmstrahlung high-level radiation above the spots; to find the mechanism of excitation of plasma oscillations leading to appearance of the outbursts of the Ist type; to take into account reabsorption for the incoherent radiation more completely; to carry out calculation of the generation mechanism of the outbursts of the IInd type by the streams of slow particles, and also to consider stable non-linear plasma oscillations in order to determine intensities of overtones. In addition, there certainly arise a number of other questions closely connected with the problem of the sporadic solar radioemission. The most important [illegible] to be the mechanism of acceleration of fast particles in corona.

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Subscriptions to the Figures.

Fig.1. Dependence of $n_{1,2}^2$ on $\rho = R/R_\odot$ (R-distance from the Sun's center, $R_\odot = 6{,}95.10^{10}$ cm-photosphere radius).

Electron concentration in the corona $N = 10^8 (1{,}55\rho^{-6} + 2{,}99\rho^{-16})$ cm^{-3}; magnetic field strength $H = H_0(1 - \frac{h}{\sqrt{h^2+b^2}})$ oersted ($h = R_0(\rho - 1)$ -height above the photosphere; $b \simeq 3.10^9$ cm -radius of the solar spot).

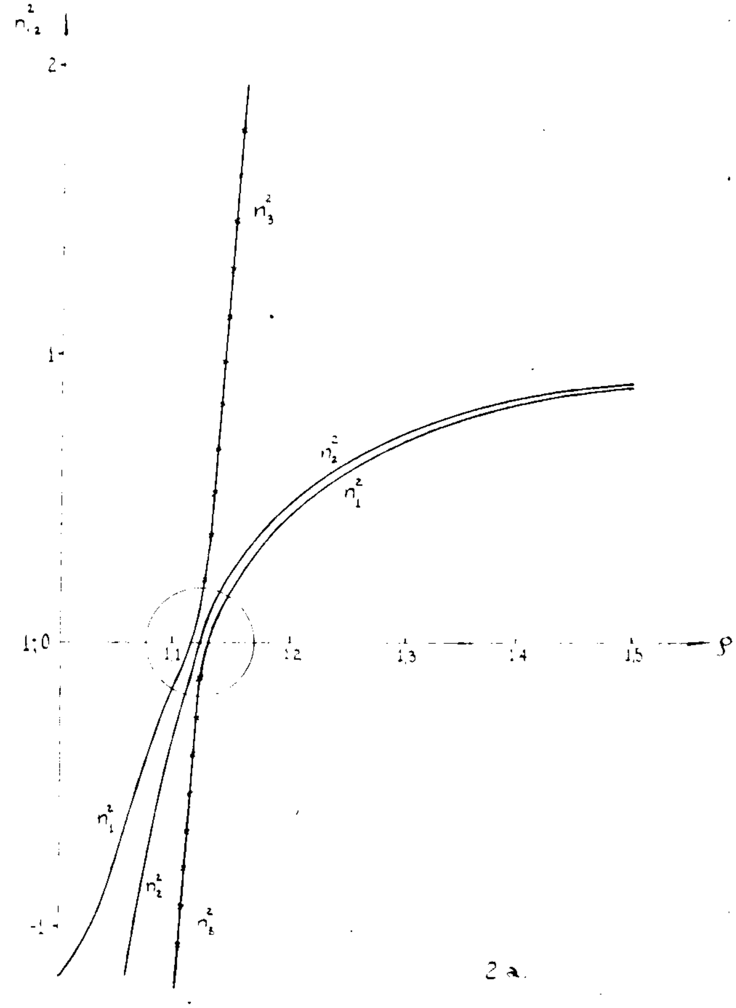
a) H_0 = 2500 oersted.

b) H_0 = 250 "

Fig.2. Dependence of $n_{1,2}^2$ on $\rho = R/R_\odot$ with the same values of N and H/H_0, as in Fig.1.

a) H_0 = 25 oersted

b) H_0 = 0.



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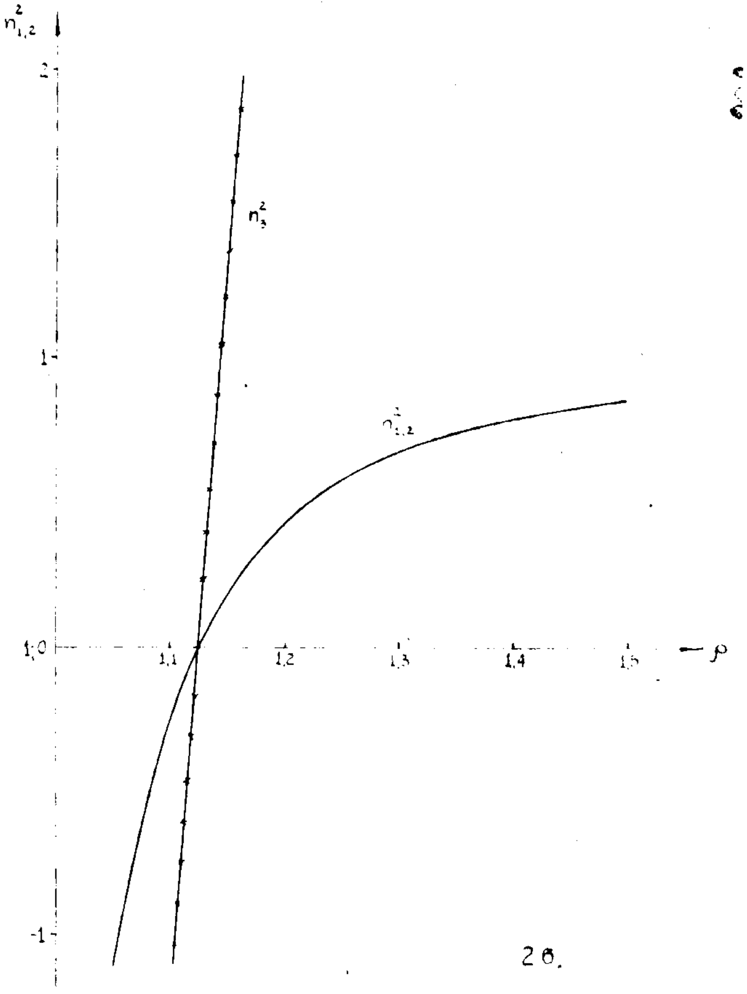
ρ

2 a.



$n_{1,2}^2$
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$n_{1,2}^2$
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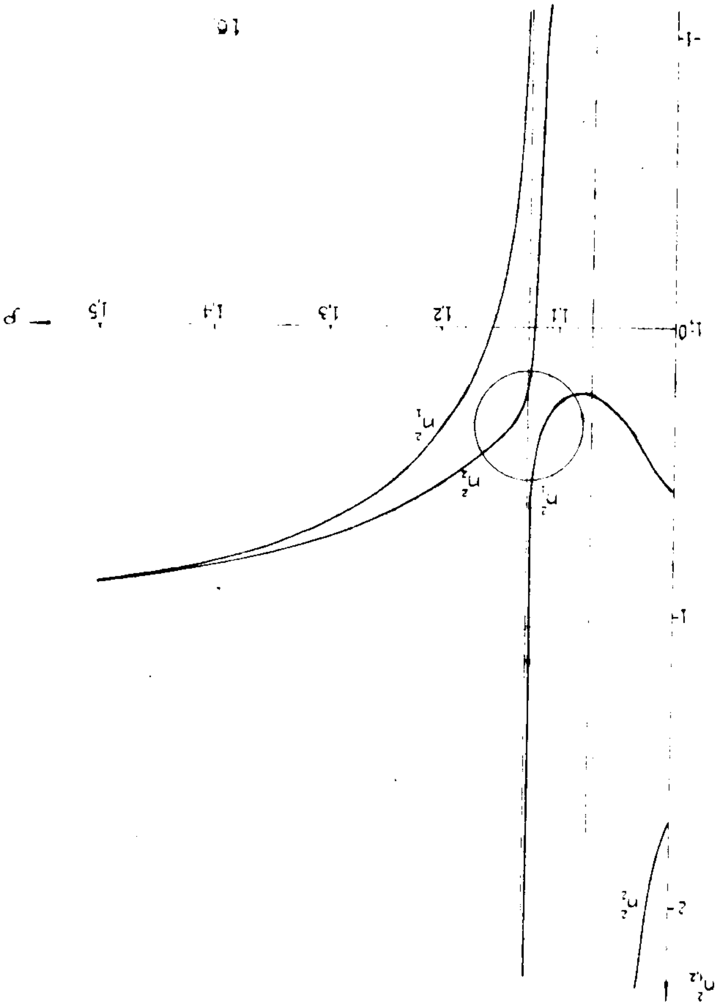

1b

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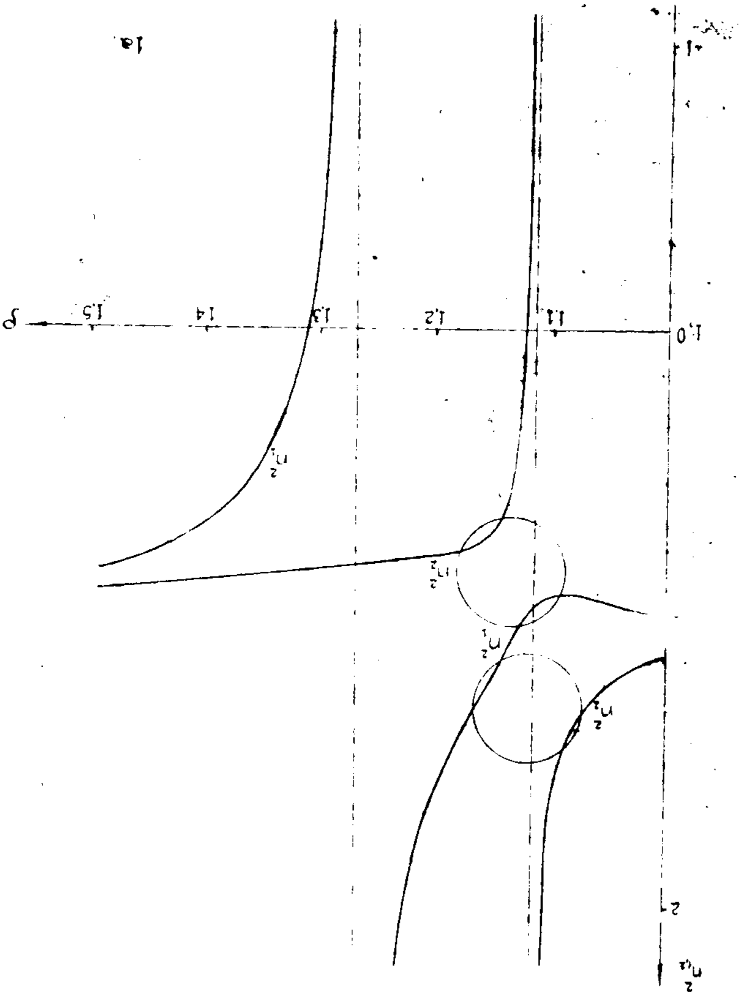
n_2^2



1a

$n_{1,2}^2$
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THE NEW DATA ON SOLAR SUPERCORONA

by V.V.Vitkevich

1. In my report I inform the results of the investigation of the most outer regions of the solar corona (which for brevity I shall call supercorona) that have been obtained during the last years.

Seven years ago in 1951 a new method of the observation was published in Doklady of Akad. of Sciences of the USSR (1,2). The idea of the mothod, which at the present time is well known, and wide spread, is that the reception of the radio emission of the Crab Nebula is produced at the time when this source of the radio emission is covered by the solar corona. This original eclipse takes place in the middle of June yearly.

Receiving radio waves passing through the regions of the solar corona, we can estimate the effects of damping, scattering refraction and make some conclusions about the structure of the most outer regions of the solar corona.

2. The first observations that gave some results were carried out in 1951. The observations of the source of radio emission were produced with the aid of the sea radio interferometer at a wavelength of 4 m in the Crimea. The intensive radio-spot that appeared on the Sun seemed to exclude the possibility of obtaining the results.

Beginning from June, 18, however, when the radio rise of the source was observed considerably earlier than that of the Sun, the intensity of the Crab Nebula could be measured. On June, 18 and 19, the amplitude of the interference lobes appeared to be less than on other days. At that time it was difficult to assert that the phenomenon was due to the influence of the outer regions of the solar corona. In the light of further results, however, it become clear that the scattering effect of radio waves on electron inhomogeneities was observed at that time (fig.1).

The investigations of the Crimean Scientific Station (and at Cambridge independently), that were carried out during the last years gave the following results. Firstly it is established that the supercorona, in the range $/4,5 \div 20/R_{\odot}$ has an inhomogeneous structure. [3,4,5,6].

Secondly, it is shown that these inhomogeneities are stationary in the sense that scattering effects are observed yearly. Thirdly, some unsymmetry of inhomogeneities is determined. The scattering effect during the second phase of the eclipse (the source is remote) is stronger than that during the first phase of the eclipse (the source is drawn near) at observations with the interference base being, in the direction east - west.

Based on last observations the characteristic of the scattering medium can be found by means of determination of the corresponding integral equation. If we adopt some size of inhomogeneities $\ell_c = 10^4$ km the electron concentrations of the inhomogeneities have the following value in equatorial and polar regions of the supercorona.

Table 1.

The values of the electron densities of the supercorona inhomogeneities at inhomogeneity size being $\ell_c = 10^4$ km

	equatorial	Polar	mean	r/R	equatorial	polar	mean
4	17700	14500	16500	11	7000	2400	[illegible]
[illegible]	16200	12300	14500	12	6000	1800	[illegible]
6	14600	12000	12600	13	5000	1400	3100
7	12700	7900	10700	14	4200	1100	2500
[illegible]	11100	6000	9000	15	3500	1000	1800
[illegible]	9700	4600	7500	16	2800	900	1400
10	8300	3400	6000	18	1700	800	1100

These data are obtained on the basis of the observations made in 1954 - 1955, and supposing the inhomogeneities are isotropik. But it is not so, as we shall show and in the future some corrections in these data must be done.

3. Now we analyze one result of observations, namely, the dependence of the angle of scattering on the wavelength. In the case of the possible use of calculations based on the approximation of the geometric optics the angle of dispersion must have a quadratic dependence due to a wavelength. Fig. gives the results of observations and calculations made in 1954. The angle of dispersion Φ_p is for various wavelengths and various angular widths $\Delta\varphi$ of lobes. The figure shows the data of the angle of dispersion reduced to a wavelength of 5,8 m (on the basis of the supposed quadratic dependence). It is seen that all curves pass comparatively near, scatter almost in all cases can be accounted for inaccuracy of measurements. Fig.3 shows the values reduced to a wavelength of 5,8 m for various wavelengths. It is seen that the dependence upon a wavelength is not observed. The greater values ϕ_p for 2,74 m wavelength are explained by the inaccuracy of the results of observations as the effect of scattering at this wavelength is comparatively small. Thus it may be considered that the dependence of the value ϕ_p upon a wavelength is quadratic.

Now we can come to the conclusion that the optical depth (thickness) τ for the longest wavelength is very small, in our case we get the optical depth (thickness) $\tau \leq 0,1$ for 7,6 m wavelength. From the last value we can estimate the upper value of the temperature of the supercorona regions for $\tau \gtrsim 1^\circ 40'$.

If ξ is inhomogeneity coefficient

$$\xi = \frac{\overline{Ne^2}}{(\overline{Ne})^2}, \quad \text{then } T_e^{3/2} > 3{,}7\cdot 10^2 \xi;$$

Supposing $r \sim 7\ R_\odot$, $Ne = 5.10^4$ we'll find for ξ = [illegible] T_e min = 5.10^4; if we accept $\xi = 9$, then Te min = [illegible]. For $r = 10\ R_\odot$, $Ne = 10^4$ and the values Te min ~~the values~~ correspondingly equal to 10^4 and 3.10^4.

It should be noted that from the observations of [illegible] 1955 and 1956 the values ϕ_p for various sizes of interferometer bases for one and the same wavelength are the same. This result confirms once more that the damping is very small. Since in calculations of the modulation depth the law of radio brightness distribution e^{-r^2/ϕ_p^2} is accepted as [illegible] to the conclusion that this law does not contradict the observation results.

4. The observations made in the period from 19[illegible] to 1956, and now to the current 1958 enable us to establish the dependence of the size of the supercorona upon the solar epoch. Such dependence is observed rather distinctly.

On the Fig.4 the sizes of the supercorona are given, [redacted] the size r_1 is determined according to the first phase of eclipse, r_2 according to the second phase. The size $r_1 + r_2$ is determined as the distance from the Sun's centre to the region where the angle of dispersion is the value $2\varphi_p$. The values for the angle $2\varphi_p$ are taken for

7,8 m wavelength according to the observations at that wavelength. It is clearly seen that the supercorona size is associated with the phase of the 11th year period of the solar activity; the supercorona size in 1957 - 1958 is approximately 20% greater than that one in 1953 - 1955. Thus the source of the origin of inhomogeneities has to be found in the solar activity. In the maximum year the matter is ejected from the Sun more actively and this perhaps is the cause of the formation of the supercorona inhomogeneities.

9. Now we refer to the question of great inhomogeneities that are in the supercorona.

The observations made in 1956 showed that in three cases (on June 12, 13; 17) a remarkable refraction of radio waves was observed which shifted the whole interference pattern on 1-2 interference lobes in comparison with the days out of the eclipse [7]. The phenomenon is explained by the presence of refraction of the order $0,5^{\circ} \div 1^{\circ}$ in the solar corona.

The direction of the refraction is as such that the apparent approach of the source to the Sun is observed. We can estimate the values of the densities of electron inhomogeneities that are responsible for the refraction of such an order. If we suppose these inhomogeneities are large-scale about (2-4) $R_{\odot}$ in diameter and are extended as coronal rays, then it is necessary to have the electronic concentration N_{er} about $(5 \div 10)\ 10^5$.

Now we refer to the results of optical observations. It is known, that coronal rays are approximately radial formations extended to many solar radii.

The electron concentration of the coronal rays [illegible] to van de Hulst's data can exceed the mean electron concentration of the corona 5-6 times. More exact calculations, however, made by G.M.Nikolsky [8] showed that this value could be increased to 10.

Nikolsky's data upon the eclipse that took place [illegible] on June 30 show that the reduction of the electron concentration within the distance $/4{,}5 \div 7/\ R_\odot$ for the eastern ray is very inconsiderable; the degree index is about 0,5. The electron concentration of the ray at the distances is determined by the value $3.4\ 10^5$. Ju.A.Ludovich [9] comes to the conclusion that the coronal [illegible] within the range $r \geq 4\ R_\odot$ can have the concentration [illegible] times larger than that one for the spherically symmetric corona.

If we use the mean values of the electron concentration of the corona for distances $(10 \div 15) R_\odot$, then we get N_e of the order of $(7 \div 2) 10^4$ [10]. Thus the ratio N_{er}/N_e $/5 \div 15/$ is very sensible. It is very near to the data that we got by an optical method.

Consequently the obtained results do not ~~only~~ contradict to the existent idea on the nature of possible coronal inhomogeneities (in the form of coronal rays) at such remote distances but they speak in the favour of the possibility of their existence at the distance of the order (10÷15) $R_\odot$.

It should be noticed that on estimation of the value N_{er} obtained by the radio method, we considered the ideal case when the ray was in the pattern plane and perpendicular to the direction of the refraction. It is more probable that the ray has a radial direction to the Sun and thus it is necessary to take into account corresponding multipliers.

6. At present there are definite indications that in some cases for the explanation of the experimental results additional considerations should be used.

Some examples to this point:

a) According to the author's observations, as it was pointed out before [5] , on the 20th of June, 1953, at [illegible] wavelength the intensity of the source under investigation increased by 80 per cent. Probably, this increase was caused by the influence of the supercorona.

b) According to Hewish (6) in 1953 at 3.7 wavelength on the 10 of June, as his diagrams show, there was decreasing of the radiation intensity of the source by 12.3 per cent, and on 11 of June the intensity restored. According to his observations on the 10 of June at 7.9 wavelength the intensity the source also decreased by 15.6 per cent (to our regret there are no observations on the 11 of June).

c) According to S[illegible]'s [11] observations of the source [illegible] with one-lobe antenna at frequency of 38 megacycles it was found that the intensity of the Crab Nebula decreased by 30 per cent at the approach of the source to the Sun [illegible] and 11.2 solar radii. But there was detected no "expansion" of the source out of the range of the [illegible] ± 1°/.

d) According to the observations carried on by the French authors Blume and Bouchet (12) at 1.77 cm. wavelength when the width of the pattern lobe of the interference array was 3'8 on the 13 of June there was detected no decrease but the increasing of the whole intensity of the source by 59 per cent. Simultaneously the widening of the sizes was observed. The refraction at that time did not exceed 30"

e) According to the data of our observations there are cases when the observation from two different bases or at two different waves are incompatible.

As we see, there are cases when the results of observations do not keep within the simple theory already given. In the case /a/ the increasing of the intensity is incomprehensible. In the case /b/ it is not quite clear why on the 11 of June the intensity restored; or more exactly, it is not clear why on the 10 of June there was a decreasing of intensity observed.

In the case /c/ the intensity decreasing is not clear, and in the case /d/ the intensity increasing is not clear. It seems to us possible to explain all the given examples of observations if we admit (as in the previous paragraph) the existence in the exterior regions of the solar corona of large electron nonuniformities with sizes of the order of one or some solar radii.

These coronal rays refracting radio waves can create noticeable changes in the intensity of radio waves (both increasing and decreasing). Coronal rays are lenses for radio-waves which focuse and defocuse them. The result of this is that the receiving energy changes essentially. Table II gives the results of some calculations.

Table II.

N_{er}	10^6	$3\ 10^5$	10^5	$3\ 10^4$	10^4	$3\ 10^3$
$1-n$	$1,5\ 10^{-2}$	$5\ 10^{-3}$	$1.5.\ 10^{-3}$	$5\ 10^{-4}$	$1,5\ 10^{-4}$	$5\ 10^{-5}$
R	200'	70'	20'	7'	2'	0'.7
F	0,33	I,I	3,3	II	33	110
I/Io	0,5	II	1,43	1,1	1,03	I,0I

N_{er} - electron concentration of the ray which is supposed to be cylyndrical, 2^0 in diameter; n - refractiv index (λ=5,8m). R - radiorefraction in minutes of arc; F - focal distance (in a.e. units) and relation values of intensity - I/Io.

As we can see, at rather considerable concentrations of the order of 10^6 the refracting effect can be rather strong