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INVESTIGATION OF VENUS' BACKSCATTERING DIAGRAM

AT 40 CM

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by

Yu. N. Aleksandrov
B. I. Kuznetsov
O. N. Rzhiga

[USSR]

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B. I. Kuzentsov
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SUMMARY

The diagram of Venus' backscattering in the wavelength of 40 cm is determined by two methods: by Doppler spectrum and by the range of energy distribution of reflected signals. Within the limits of precision linked with the limited resolution of the initial spectrum, both methods gave identical results.

The Doppler spectrum and the range distribution of signals reflected by Venus are in good agreement with the theoretical dependences computed in the assumption that the bulk of radiowave energy is specularly reflected, and that the spatial altitude correlation on the surface of Venus is defined by an exponential function. The Gauss function gives no coincidence.

A certain part of energy is diffusively scattered by elements of the surface, whose dimensions are commensurate with the wavelength. The smoothness factor of the diffusively scattering surface is comprised between 0 and 1.

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* *

1. INTRODUCTION. The radiowaves, reflected by separate portions of the sky, have a different time lag of arrival and a different Doppler frequency shift. This phenomenon is used at radar investigation of planet surface. Knwoing the distance to a specific portion of the surface or its radial velocity relative to locator, it is possible to separate the signals reflected by that area and determine the energy density of the waves corresponding to them. By the combination of measurements conducted for various portions of surface it is possible to find the planet's backscattering diagram. This function establishes a depe de ce of energy density of waves reflected in the direction of the locator by a certain portion of the surface on the angle of incidence, or, which is the same, on the angle of reflection.

For Venus, which is a planet with very slow rotation, the difference of

(*) ISSLEDOVANIYE DIAGRAMMY OBRATNOGO RASSEYANIYA VENERY NA VOLNE 40 CM radial velocities is very small. As in the case of the Moon, this results in only in insignificant widening of the the spectral line of reflected waves. This is one of the causes inducing most of researchers to determine Venus' backscattering diagram from observations of energy distribution of reflected waves by range, where the required resolution is more easily ensured. During radar observations of Venus in 1964 in the 40 cm wavelength [1, 2], such precision was obtained during time lag and Doppler spectrum of reflected signal measurements that it became possible to compare among themselves the results of determination of Venus' backscattering diagram obtained at 40 cm by two different methods.

2. Approximation of the Backscattering Diagram. The results of radar investigations of Venus (see, for example, [3]) point to the fact that the basic backscattering toward locator is given by the regions of the planet situated near the center of the visible disk, which is a phenomenon characteristic of specular reflection. The polarization of the bulk of energy of radiowaves reflected by Venus also corresponds to specular reflection. Depolarization at 40 cm involves less than ten percent (10%) of the whole returning energy [4]. It may be assumed that specular reflection is conditioned by surface elements, the dimension and curvature radius of which are much greater than the wavelength. These elements yield an intense backscattering when they occupy relative to the ray a perpendicular position.

A large number of works (see reviews [5, 6]) have been devoted to the theoretical investigation of the backscattering diagram of the Moon and planets in the case when some characteristic dimension of roughnesses or surface inequalities is much greater than the wavelength. In such investigations the statistical properties of the surface are often described with the aid of spatial autocorrelation function $\rho(l)$ and of standard altitude deflection σ_h relative to average surface, the altitude distribution being assumed to be normal. Considered were autocorrelation functions of two forms:

- the exponential

$$\rho(l) = \exp(-|l| / l_0) \tag{1}$$

- and the Gaussian

$$\rho(l) = \exp(-l^2 / l_0^2). \tag{2}$$

where l_0 is the characteristic dimension indicating at what distance the correlation decreases e times. In investigations of reflection characteristics of certain terrestrial regions [7], of the Moon [5] and Venus at 23 cm [8], a good coincidence was revealed between the backscattering diagram and the theoretical dependence computed for the exponential autocorrelation function.

Examining the reflection process of electromagnetic waves from a dielectric surface having an extended wavy relief of random profile, Hagfors [9] found that if the average curvature of slopes is not too great, the bacscattering diagram in case of exponential autocorrelation must have the form

$$P_2(\varphi) = (\cos^4\varphi + C\sin^2\varphi)^{-3/2}, \tag{3}$$

where ϕ is the angle between the incident ray and the normal to the sphere, i.e. mean planet surface at the given point, and $C = (\lambda l_0 / 4\pi\sigma_h^2)^2$.

This formula is valid for angles not too large, since no account was taken of the mutual shadowing of reflecting elements when the conclusion was derived. Its nonaccounting results in that the function does not become zero as $\phi \to \pi/2$.

The intensity of specular reflection decreases rapidly in the direction toward the limb, where the probability of ray encounter at right angle with a sufficiently extended element of the surface is small. Near the limb the character of reflection changes [5, 10] and radiowave scattering begins to prevail on elements of the surface, whose dimensions are commensurate with the wavelength, which induces a "diffusive reflection". In this case, the backscattering diagram may be described by the dependence

$$P_\vartheta(\varphi) = \cos^\vartheta \varphi. \tag{4}$$

In surface photometry, parameter $(\vartheta - 1)$ bears the name of smoothness factor [11]. This dependence describes fairly well the backscattering for numerous types of rough surfaces often encountered in optics. Thus, for ort otropic scattering, which is described by Lambert law, $\vartheta = 2$, and for scattering, at which surface brightness is not dependent on the angle ϕ $\vartheta = 1$. The last type of scattering may be observed on the Moon during fullmoon, when the brightness of any detail of the lunar disk is determined only by the reflectivity of the matter at the given spot [12].

3. Determination of the Backscattering Diagram from Energy Distribution over Distance. Let us admit that for an emission of specific wavelength the entire surface of the visible hemisphere of the planet constitutes statistically uniform structure and has identical electrical properties. We may then establish that the energy distribution of a reflected signal over distance P(y) and the backscattering diagram $P(\phi)$ must be linked by the relation

$$P(y) = P[\varphi(y)],$$
$$\varphi(y) = \arccos(1 - y), \quad 0 \leqslant y \leqslant 1, \tag{5}$$

where y is the distance counted along the visual ray from a point of the planet nearest to observer (from the center of the visible disk) and expressed in planetary radii. The lines of equal distance form in projection on the disk concentric circumferences.

With the aid of relation (5) one may compute the expected distribution P(y) for the aforementioned models, and, varying the parameters determining the initial depedence $P(\phi)$,obtain the best possible agreement with experimental data.

In the case when the spatial correlation of altitudes is given by an exponential function, we shall utilize for the approximation of the specular component of the backscattering diagram, instead of relation (3), the more simple one

$$P_3(\varphi) = (1 + C\sin^2\varphi)^{-3/2}. \tag{6}$$

For great values of parameter C that take place for Venus and the Moon, both relations lead to a sufficiently close result (*).

Substituting relation (6) into Eq.(5), we obtain

$$P_3(\varphi) = [1 + Cy(2 - y)]^{-3/2}. \qquad (7)$$

Hence follows directly that the quantities $[P_3(y)]^{-2/3}$ and $y(2 - y)$ are linked among themselves by a linear dependence. If relation (6) is sufficiently fully describing the backscattering diagram of Venus, the points of the observed distribution in the $[P_3(y)]^{-2/3}$ and $y(2 - y)$ system of coordinates must lie on a straight line, of which the inclination is determined by parameter C.

The distribution of energy of Venus' reflected signals by range in the 40 cm wavelength was obtained in 1964 [1] for annular zones within the limits of one-third of planet's radius (**). This distribution is represented in Fig.1 by circles, using the aforementioned coordinates. The distribution for the area of planet's surface, nearest to Earth, which was obtained with higher resolution (to 10^{-3} of Venus' radius), is plotted separately by squares.

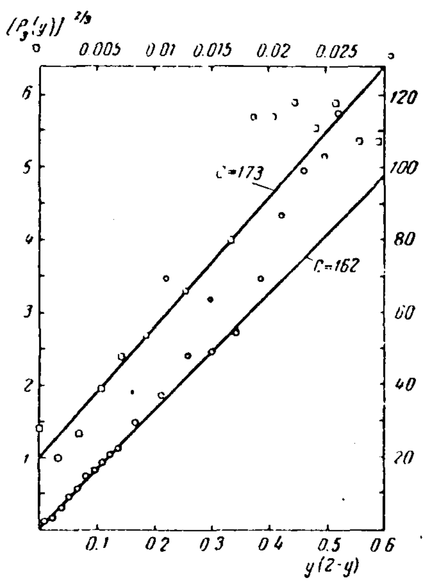

Fig.1 Linearization of the specular component in the distribution of energy of reflected signals by range. Circles correspond to annular zones distant from planet's point closest to observer by a depth of 0.5 $R_♀$; squares indicate separately the data for the initial portion of surface

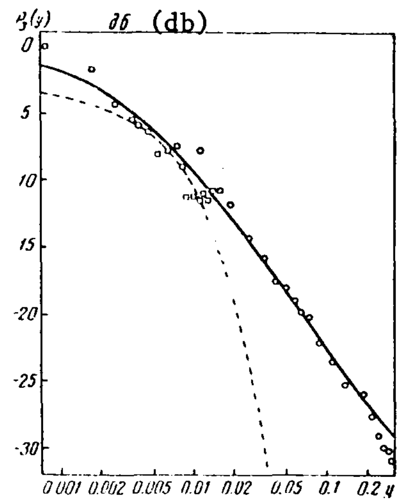

Fig.2. Energy distribution of reflected signal by range [1] and approximating curves at exponential (solid line, C = 165) and Gaussian (dashes) autocorrelation function of altitudes.

(*) At $\phi = 0$, $P_3(0) = 1$ in both cases; at $\phi = \pi/2$ we have $P_3(\pi/2) = C^{-3/2}$ (3), $P_3(\pi/2) = (C+1)^{-3/2}$ (6). The maximum difference taking place when $\sin\varphi \approx \sqrt{2/C}$, at C = 100 does not exceed 2.6 percent. (**) This region occupies a part of the visible disk with dimension of 3/4 of the diameter.

As may be seen from the drawing, the experimental points are rather well concentrated near the corresponding straight lines. Both groups of measurements yield somewhat different values of parameter C, of 165 as an average. The approximating curve for this value of C is shown in Fig.2 alongside with the experimental points.

Fot the case when the spatial correlation of altitudes is determined by a Gaussian function (see (2)), Hagfors [9] obtained

$$P_3(\varphi) = \frac{\exp(-B\,\mathrm{tg}^2\,\varphi)}{\cos^4\varphi}, \tag{8}$$

where

$$B = \frac{l_0^2}{4\sigma h^2}.$$

From relations (5) and (8) we find

$$P_3(y) = \frac{\exp B[1-(1-y)^{-2}]}{(1-y)^4}. \tag{9}$$

The taking of logarithm from this equality ascertains the direct proportionality between log n $[(1-y)^4 P_3(y)]$ and $[1-y)^{-2}]$; the proportionality factor is B.

As was found, the utilization of Gaussian function must yield a significantly worse result by comparison with the exponential function.

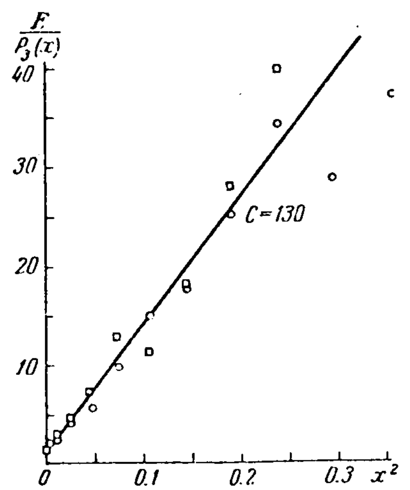

Fig.3. Linearilzation of the specular component in the spectrum of the reflected signal. Circles correspond to the "approaching" half of Venus' disk and squares to that "drifting away"

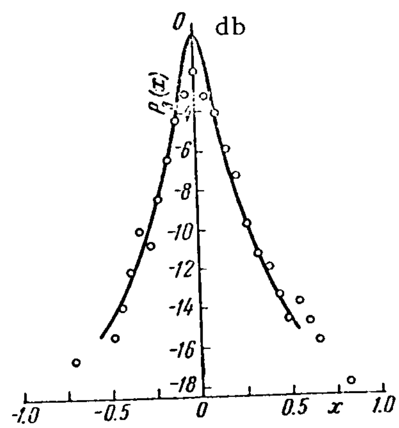

Fig.4. Doppler spectrum of a signal reflected by Venus [2] and the approximating curve C = 130

Plotted by dashes in Fig.2 is the approximation curve which represents satisfactorily the experimental points at medium ranges, diverging at the beginning and at the end of the graph. Varying B, it is possible to obtain a coincidence for small and great values of y, but for the remainder of the points the divergence will then be still greater.

The investigation of the diffusive component on the basis of the distribution of P(y), brought out in [1], could not be conducted because specular reflection prevails in those zones for which such a distribution is obtained.

4. Determination of the Backscattering Diagram by the Doppler Spectrum. For a uniform sphere it follows from geometrical correlations that the Doppler spectrum of reflected signals P(x) and the backscattering diagram P(ϕ) are linked with a precision to a constant multiplier by the relation

$$P(x) \div \int_0^{\pi/2} P[\varphi(x, \varkappa)]\, d\varkappa,$$

$$\varphi(x, \varkappa) = \arccos\left(\sqrt{1 - x^2}\sin\varkappa\right), \quad |x| \leqslant 1, \tag{10}$$

where x is the Doppler frequency shift, related to the maximum value.

The lines of constant Doppler shift, conditioned by planet rotation, form on the latter's disk a network of straight parallel projection of visible rotation axis on the disk. The value of the Doppler shift is proportional to the distance of the given part of the disk to the projection axis. Parameter x expresses these distances in planet's radii.

Substituting into Eq.(10) the approximate relation (6) describing the specular component of the backscattering diagram in the case when the spatial altitude correlation is assigned by the exponent, and performing integration, we shall obtain

$$P_3(x) = \frac{E}{1 + Cx^2}. \tag{11}$$

The modulus of the total elliptical integral of 2nd kind is

$$k = \sqrt{\frac{C}{C+1}(1 - x^2)} \approx \sqrt{1 - x^2}.$$

For great C, for which relations (6) and (11) are valid, the dependence P(x) is determined mainly by the denominator; the numerator increases monotonically from 1 to $\pi/2$ as x varies from 0 to 1.

It follows directly from relation (11) that now a linear dependence must exist between the quantities $E/P_3(x)$ and x^2. The inclination of the corresponding straight line is also determined here by parameter C.

As may be seen from Fig.3, in the indicated system of coordinates the Doppler spectrum of Venus-reflected signals, brought out in the work [2], satisfies a straight line with angular coefficient C = 130. The experimental points are scattered near that line in a random fashion and do not show regular deviations.

The averaged spectrum of Venus-reflected signal is plotted in Fig.4, alongside with the theoretical dependence approximating the specular component, and it is plotted in polylogarith ic scale at C = = 130. The discrepancy between the approximating curve and the experimental points at the center may be explained by the insufficient resolution at harmonic analysis which results in the smoothing out of the the central peak.

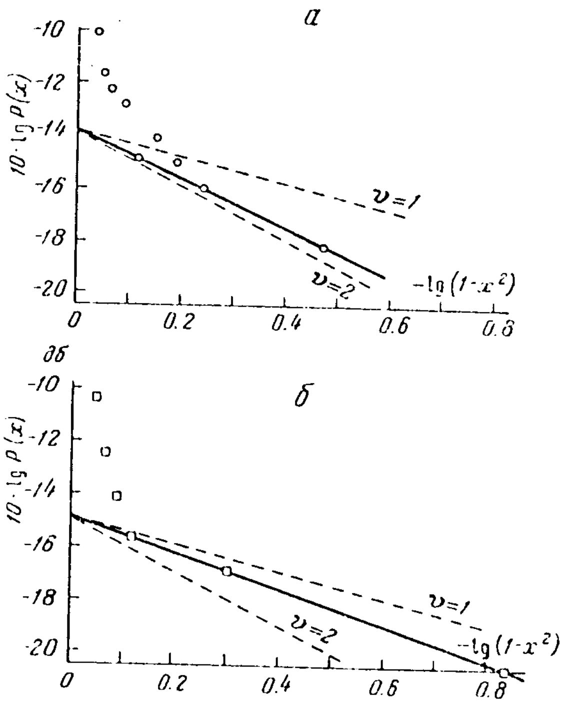

Fig.5. Linearlizarion of the diffusive component of Venus-reflected signal, separately for the "approaching" (circles) and "drifting away" (squares halves of planet's disk. The scale along the ordinate axis and the origin of the count are the same as in Fig.4

Therefore the distribution of energy by range and the Doppler spectrum of reflected signals give a somewhat different value of parameter C*). More reliable must apparently be the value of C obtained from energy distribution by range, which has a high degree of resolution. It is probable that an improved resolution is likely to result in the decrease of discrepancy at harmonic analysis.

The Doppler spectrum of the diffusion component, corresponding to the dependence (4), can be computed without resorting to integration (see (10)):

$$P_{д}(x) = (1-x^2)^{\vartheta/2}. \quad (12)$$

The taking of logarithm of this relation will allow us to detect the linear dependence between log $P_{д}(x)$ $\sim$ $\log(1-x^2)$ with the angular coefficient $\vartheta-1$ The experimental spectrum is plotted in Fig. 5 in these coordinates. The points nearest the limb correspond to dependence (12) when parameter ϑ varies from 1 to 2. Because of the low level of the diffusive component, a more specific conclusion is difficult to draw.

**** T H E   E N D ****

Inst. of Radio Engineering and Electronics
of the USSR Academy of Sciences

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... References follow .../

(*) see this infrapaginal note on next page.

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(*) [From page 7.] This discrepancy cannot be explained by the difference in the reflecting properties of Venus' surface. Basic measurements of energy distribution of reflected signals by range within the bounds of $1/R_{♀}$ were conducted in the course of 2 days (11 and 12 June 1964); the spectral measurements were performed on 12 June. In the course of 24 hours the longitude of the central meridian of Venus, which has a very slow rotation (according to radar observations, the sidereal period of Venus constitutes 250 days at inverse rotation [4, 10]) could have changed by no more than 1°, and, consequently, during measurements the planet was turned toward the Earth by one and the same hemisphere, i. e. the same Venus' hemisphere was facing the Earth during the entire measurement period.