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RADIATION AND REFLECTIVITY OF VENUS ON DECIMETER WAVES

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Abstract

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Astronomy

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RADIATION AND REFLECTIVITY OF VENUS ON DECIMETER WAVES

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The most reliable hypothesis concerning the nature of the intense radiation of Venus in the radio range is apparently the greenhouse hypothesis, according to which the observed radiation is emitted by the planet' s surface, heated to a high temperature as a result of the action of a greenhouse mechanism in its lower atmosphere ([1]). It is assumed here that the strong greenhouse effect is due to the experimentally proven presence on Venus of carbon dioxide and water vapor ([1,2]). The greenhouse hypothesis has made it possible to explain numerous experimental results on the radio emission of the planet, such as the frequency and phase dependence of the intensity of its radiation at centimeter and millimeter wavelengths ([3,4]), results obtained when scanning the disk of Venus from Mariner 2 ([5]), and so on.

Recently, however, new data have appeared that have not yet been explained within the framework of the greenhouse hypothesis. These include, in particular, the results of measurements of the brightness temperature of Venus T_b in the decimeter range, which in the wavelength interval 30-70 cm proved to be, at least, several tens of degrees lower than at shorter wavelengths (see, for example, ([6–8])).

A. D. Kuzmin and B. J. Clark ([9]) detected polarization of the radiation from the limb of the disk of Venus at a wavelength of 10.6 cm and found that the degree of polarization corresponds to a value of the dielectric constant ε of the surface rocks equal to 2.5. Estimates of ε were also made on the basis of radar measurements of the reflectivity of the planet' s surface at decimeter wavelengths. The corresponding calculations led to the value $\varepsilon \approx 4$ ([10]), which differs substantially from the data of ([9]). In ([11]) this discrepancy between the values of the dielectric constant of the surface layers of the soil on Venus, determined by two independent methods, is considered as an indication that some part of the received radio emission of the planet is determined by its cloud cover.

It can be shown, however (without introducing a new radiating layer into the model of the planet's atmosphere, as was done in ([11])), that the above-mentioned experimental results are consistent with the greenhouse hypothesis. Let us assume that the upper cover of Venus, responsible for its radiation in the decimeter range, consists of a solid rocky substrate covered by a thin layer of material of lower density (Fig. 1). The brightness temperature of the surface radiation at wavelength λ in a direction characterized by the angle θ, $T_\mathrm{b}(\lambda, \theta)$, will then be determined by the radiation of the upper layer and by the radiation of the substrate attenuated in passing through the upper layer, i.e.,

$$T_\mathrm{b}(\lambda,\theta) = [1-R(\varepsilon_1,\theta)]T_\mathrm{p}\{1-\exp[-\gamma_1(\lambda)d_1/\cos\theta_1]+(1-R_1(\varepsilon_2/\varepsilon_1,\theta_1))\exp[-\gamma_1(\lambda)d_1/\cos\theta_1]\}. \tag{1}$$

Here T_p is the thermodynamic temperature of the upper cover; d_1 is the thickness of the upper layer; ε_1 and γ_1 are, respectively, the dielectric constant and absorption coefficient of the substance forming it; ε_2 is the dielectric constant of the substrate material; $R(\varepsilon_1, \theta)$ is the power reflection coefficient of the planet' s surface; $R_1(\varepsilon_2/\varepsilon_1, \theta_1)$ is the power reflection coefficient of the interface between the upper layer and the substrate; the angles θ and θ_1 are related by

$$\sin\theta = \sqrt{\varepsilon_1}\sin\theta_1.$$

The absorption coefficient $\gamma_1(\lambda)$ is determined by the expression (12)

$$\gamma_1(\lambda) = 2\pi(\mathrm{tg}\,\Delta/\rho_1)\rho_1\sqrt{\varepsilon_1}/\lambda, \tag{2}$$

where ρ_1 and $\mathrm{tg}\,\Delta$ denote, respectively, the density and the loss-angle tangent of the substance that forms the upper layer. An analogous structure of the upper cover was considered in works (13,14) to explain the emission characteristics of the Moon in the radio range. It should be noted, however, that the authors (13,14) assumed the thickness of the upper layer to be so small that absorption of radio waves in it could be neglected.

Fig. 1

To determine the brightness temperature of the radiation of Venus, expression (1) must be integrated over the solid angle Ω_Venus occupied by the planet:

$$T_{\mathrm{b}\Omega}(\lambda) = \frac{1}{\Omega_\mathrm{Venus}}\int_{\Omega_\mathrm{Venus}} T_\mathrm{b}(\lambda,\theta)\,d\Omega_\mathrm{Venus} = \int_0^{\pi/2} T_\mathrm{b}(\lambda,\theta)\sin 2\theta\,d\theta. \tag{3}$$

It follows from expressions (1)–(3) that, as λ increases, the contribution of the upper layer to the total radiation of the planet decreases and, conversely, the contribution of the substrate increases. On emerging into the atmosphere, part of the radiation of the upper layer is reflected from the surface back into the medium. The radiation of the substrate, before emerging outward, undergoes partial reflection twice: at the boundary between the upper layer and the substrate and at the boundary between the atmosphere and the upper layer. Therefore, with increasing λ, there should be a decrease in the value of $T_{\mathrm{b}\Omega}$, which, evidently, will be the greater the smaller ε_1 is or the larger the ratio $\varepsilon_2/\varepsilon_1$.

Figure 2 presents the results of calculations of the brightness temperature of Venus for a two-layer model of the structure of its upper cover. The calculations of $T_{\mathrm{b}\Omega}$ were carried out by means of formula (3) in the wavelength interval 5-75 cm. It was assumed that the upper layer consists of granite, and for its parameters the values $\operatorname{tg}\Delta/\rho_1 = 0.004$ $^{(12)}$, $\varepsilon_1 = 1.5$, $\rho_1 = 0.5\ \mathrm{g}\cdot\mathrm{cm}^{-3}$, $d_1 = 100$, 300, and 500 cm were taken. The indicated values of ε_1 and ρ_1 satisfy the relation between the dielectric constant and the density of crushed granite that is given in $^{(15)}$. For ε_2, the values 9 (granite) and 10 (sandstone) were adopted. The dependences $R(\varepsilon_1, \theta)$ and $R_1(\varepsilon_2/\varepsilon_1, \theta_1)$ were determined with the aid of the Fresnel reflection coefficients.

Figure 2 also gives the experimental results of measurements of the brightness temperature of Venus. Comparison of the curves obtained for $T_{\mathrm{b}\Omega}$ with the results of measurements shows that the two-layer model of the near-surface soil layers makes it possible to explain the decrease in the planet' s brightness temperature on decimeter waves.

Figure 3 presents the dependences of the reflectivity of Venus on λ, calculated for the case of normal incidence of the wave on the surface ($\theta = 0$). It is seen from this that the two-layer structure of the upper cover also agrees with the experimentally found values of R_{Venus}.

The model considered for the structure of the near-surface soil layers on Venus also makes it possible to explain the results of work $^{(9)}$. In the experiment Kuz' min and Clark considered radiation from the edges of the planet' s disk, where the angles θ and, consequently, θ_1 differ significantly from zero. Therefore, at the edges of the visible disk the radiation is subject to strong attenuation, i.e., the radiation from the edges is determined mainly by the upper layer, which has a low dielectric permittivity. Thus, the discrepancy between the values of ε determined from radar and polarization experiments may be due to the fact that in one case the signal reflected from the center of the visible disk of the planet was taken, while in the other—the radiation from its edges.

Good physical analogues of the considered two-layer model of the structure of the upper cover of Venus are apparently a sandy desert or rocky rocks covered with porous products of volcanic eruptions. Let us note that the assumption of a two-layer structure of the upper cover is also consistent with the low reflectivity of Venus ($\sim 1 \div 2\%$), measured at wavelengths of 3.6 cm and 3.8 cm (^{16,17}).

Fig. 2. Dependence of the brightness temperature of Venus on wavelength. $T_1 = 670^\circ\mathrm{K}$, $\varepsilon_1 = 1.5$, $\rho_1 = 0.5\ \mathrm{g/cm}^3$:
1—$d_1 = 100$ cm, $\varepsilon_2 = 9$; 2—$d_1 = 100$ cm, $\varepsilon_2 = 9$; 3—$d_1 = 500$ cm, $\varepsilon_2 = 9$; 4—$d_1 = 100$ cm, $\varepsilon_2 = 10$; 5—$d_1 = 300$ cm, $\varepsilon_2 = 10$; 6—$d_1 =$

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500 cm, $\varepsilon_2 = 10$.
Circles are the results of measurements of T_{bVenus}.

Fig. 3. Dependence of the reflectivity of Venus on wavelength.
1—$d_1 = 100$ cm, $\varepsilon_2 = 9$; 2—$d_1 = 300$ cm, $\varepsilon_2 = 9$; 3—$d_1 = 500$ cm, $\varepsilon_2 = 9$; 4—$d_1 = 100$ cm, $\varepsilon_2 = 10$; 5—$d_1 = 300$ cm, $\varepsilon_2 = 10$; 6—$d_1 = 500$ cm, $\varepsilon_2 = 10$.
Circles—results of measurements of R_{Venus}.

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