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Abstract

Full Text

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RADIO-ASTRONOMICAL STUDIES AND THE IONOSPHERE OF VENUS

(Presented by Academician E. K. Fedorov, 7 XII 1964)

As is known, several hypotheses have been advanced to explain the high temperatures of Venus' own radio emission. The greenhouse and eolosphere hypotheses and their later modifications assume high surface temperatures, whereas ionospheric models attribute the high temperatures of centimeter radio emission to the upper layers of the atmosphere.

In the author' s previous work (^1) it was shown that the model of a well ionosphere proposed by A. D. Danilov and S. P. Yatsenko (^2, ^3) can explain practically all the available radio-astronomical data on Venus. During the past year new data have appeared in the literature that are of interest for the problem of the origin of Venus' own radio emission and its connection with the planet' s ionosphere. The present work is devoted to a consideration of these data.

In the work of N. N. Soboleva and Yu. N. Pariisky (^4), an analysis is given of data on the polarization of Venus' own radio emission at a wavelength of 10.6 cm, obtained by Sillštadt et al. (^5). This analysis showed that the indicated polarization data can be explained if one assumes the presence around Venus of an ionosphere with an electron content along the line of sight of 10^{16} cm^{-2}. If the effective thickness of the ionosphere is approximately 100 km, the conclusion of Soboleva and Pariisky (^4) means that in the ionosphere of Venus there are electron concentrations of the order of 10^9 cm^{-3}, i.e., precisely those required for the ionospheric model. It is necessary, however, to note that the reliability of the polarization value measured in (^5) ($\sim 0.6\%$) is very low.

Clark and Spencer (^6) investigated, with the aid of a variable-baseline interferometer, the distribution of radio emission with $\lambda = 9.5$ cm over the disk of Venus and found that this distribution cannot be uniform or show limb darkening. This, apparently, is an argument against the assumption that the planet' s surface is the source of radiation at $\lambda = 9.5$ cm, since in the case of thermal radiation from the surface, limb darkening of the disk of Venus should be observed. At the same time, if the well model of the ionosphere is correct, one cannot in general say a priori what the distribution of brightness temperatures over the disk will be, since it will be determined by the distribution of ionized "clouds" in the ionosphere, which is as yet unknown.

As was already pointed out (^1), in the work of Priester et al. (^7) an inverse correlation was found between the value of the astronomical unit, measured at

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Fig. 1

Figure 1: Fig. 1

Fig. 2

Figure 2: Fig. 2

70 cm, and the flux of solar radiation at a wavelength of 10.7 cm, which is a good indicator of solar activity. The authors (ˆ7) explain the observed correlation by the reflection of radio waves with $\lambda = 70$ cm in the ionosphere of Venus, which expands with increasing solar activity and contracts when the latter decreases, as happens with the terrestrial ionosphere.

Figure 1 gives an analogous comparison for the value of the reflection cross section σ, obtained by Goldstein (ˆ8) by radar at 12.5 cm during the 1962 conjunction. As emphasized in (ˆ8), the meas–

the measured quantity σ undergoes day-to-day variations exceeding the expected measurement errors. In our view, this fact in itself argues in favor of the presence, along the path of the radiation used in the radar observations, of a dense ionosphere, since it is difficult to suppose a noticeable change in the reflection characteristics of the surface. In addition, comparison of the value of σ, taken from Fig. 2 of work (^{8}), with the value of the solar radio-emission flux at a wavelength of 10.6 cm shows (see Fig. 1) that these quantities vary in antiphase. The uncertainty for the first days of November, where the σ curve is not drawn at all, and for 9-15 X, where the σ curve is drawn with some uncertainty, apparently cannot change the general conclusion about the mutually opposite variation of the quantities $P_{\odot}^{10.7}$ and σ.

Fig. 1

This result is difficult to explain from the point of view of free passage of radio waves through the ionosphere and reflection from the surface. From the point of view of a hole model of the ionosphere, however, it is explained quite naturally. According to this model (see Fig. 4 in (^{1})), the reflection of radiation that has passed through regions of the ionosphere free of dense clouds occurs from the surface of Venus. In this case the reflection cross section must be directly proportional to the true reflection coefficient of the surface material and to the hole coefficient of the ionosphere, i.e., to the relative fraction of hole and dense regions on the planet' s disk. With increasing solar activity, the area of regions that are optically dense for radiation with $\lambda = 12$ cm should increase, thus leading to a decrease in the reflection cross section obtained by radar observations at these wavelengths.

Fig. 2

James and Ingalls (^{9}) point out that the fact that the increase in the reflection cross section at wavelengths of 7.85 m ($\sim 15\%$) relative to the reflection cross section for waves of the decimeter range ($\sim 10\%$) can be explained by a dense ionosphere, although in that work the more probable explanation of the increase in the cross section at 7.85 m is considered to be the presence of a surface layer transparent for meter-range waves but opaque for centimeter waves.

In October-December 1962, Buash et al. (^{10}) measured the temperature of Venus' s own radio emission at wavelengths of 13 and 21 cm. An increase in the radiation temperature at both wavelengths was registered, which the authors (^{10}) associate with an increase in solar activity on 13-17 XI. The latter may probably serve as an indication of a connection

of the radiation in the wavelength interval under consideration with the ionosphere, since in the case of the greenhouse model no such dependence should be observed, because in the visible region of the spectrum the intensity of solar radiation does not undergo any noticeable change.

Since the question of the dependence of the brightness temperatures obtained at different wavelengths on the flux of solar radio emission is of great interest, we attempted to find a dependence on $P_{\odot}^{10.7}$ of the mean values T_{b} shown in Fig. 2. However, most of these values were obtained by averaging temperatures measured over several months, during which the radiation flux varied, and therefore the effect sought must be smoothed out. Moreover, relatively few measurements were carried out at high solar activity—the greater part of the experiments belongs to recent years, when solar activity was low. It is therefore possible to indicate only certain qualitative conclusions. Thus, the points of Basho et al. (^{10}), situated somewhat higher than the others, at 13 and 21 cm, and those of Gibson and Corbett (^{11}) at 1.35 cm, were obtained during one and the same period, when the authors (^{10}) observed an increase of T_{b} at 21 and 13 cm during an increase of solar activity; of all the points in the 8-mm region, at a high activity index ($P_{\odot}^{10.7} \sim 250$–$300$ units) the point at 8.6 mm (^{12}) was obtained ($T_{\text{b}} = 410°\text{K}$), giving the highest temperature. Drake' s points (^{13}) at 21 and 40 cm (528 and 400°K, respectively) were obtained, on the contrary, at very low activity ($P_{\odot}^{10.7} \sim 80$ units). For a detailed investigation of the question it is, of course, necessary to compare the values of T_{b} by days of observation with the value $P_{\odot}^{10.7}$, or with other activity indices.

The values T_{b}^{13} and T_{b}^{21} obtained by Drake (^{13}) may evidently, in themselves, argue against the greenhouse model or other models that assume the planet' s surface to be the source of radiation. In the case of emission by the surface, the brightness temperature should be constant for $\lambda > 2$–3 cm, as has hitherto been assumed in the greenhouse model. It cannot be assumed, as Drake did, that the decrease of temperature at long wavelengths is caused by a decrease of the emissivity of the surface, since radar data give constancy of the reflection coefficient of the surface in the region 12-70 cm. Moreover, at 21 cm there are measurements by other authors that give temperatures of the order of 600°K, close to the temperatures at 3 and 10 cm and to Findlay' s point (^{14}) at 40 cm; therefore, if Drake' s measurements (^{13}) are correct, one can speak only of variations of the brightness temperature at 21 and 40 cm.

Similar variations of brightness temperature, as is known, have also been observed in a number of other experiments. Thus, in the paper by A. E. Salomonovich and A. D. Kuz’ min (^{15}) it is stated that on some days at 10 cm very high brightness temperatures of Venus were observed, exceeding 1500°K, which led to a high mean value of the temperature obtained, $T_{\mathrm{b}} = 690°\mathrm{K}$.

In the paper by Clark and Spencer (^{6}), high values are given for the brightness temperature of the radiation of Venus at 21 cm, obtained in three experiments during one day (27 IX 1962): 908, 865, and 849°K. These values greatly exceed the several-day average value $T_{\mathrm{b}} = 616°\mathrm{K}$ obtained in the work under consideration (^{6}). In both cases the deviations of the temperatures from the mean values greatly exceeded the instrumental errors of the measurements. This may indicate the existence of real variations in the temperature of the intrinsic radio emission of Venus, especially at centimeter and decimeter wavelengths. The presence of such variations is rather difficult to explain from the point of view of surface emission, since a rapid change in the temperature or emissivity of the latter is unlikely. At the same time, such variations are quite understandable if the radiation in the centimeter and decimeter ranges

is connected with the ionosphere, which, as is known from studies of the terrestrial ionosphere, is a very dynamic formation.

Thus, at present there are a number of indications that the results of radioastronomical studies of Venus are apparently connected with its ionosphere. This circumstance must be taken into account in interpreting the experimental data, regardless of what model is used to explain the complete spectrum of brightness temperatures of the radio emission of Venus.

As has already been pointed out (^{1}), in the well-type model of the ionosphere no substantial difficulties arise in explaining the constancy of the reflection cross section obtained at wavelengths of 12-70 cm. The results of radar measurements at 7.85 m are also fully explained by this model. As for the possibility of explaining the experimental spectrum T, then, as shown in the work of A. D. Kuzmin (^{16}), the presence of three free parameters makes it possible to bring practically any spectrum of brightness temperatures into agreement with the theory, although the parameters themselves cannot be determined without additional assumptions. As an example, Fig. 2 gives curves 1 and 2, which yield somewhat different temperatures in the millimeter region and in the region $\lambda >$ 10 cm. These curves were constructed on the basis of the well-type ionosphere model under the assumption that half of the disk of Venus is covered by dense ionized clouds (filling factor 0.5), while the remaining parameters for curves 1 and 2 are, respectively: $T(1-R) = 380$ and 350° K; $T = 820$ and 900° K, where T and R are the true temperature and the reflection coefficient of the surface of Venus, and T is the temperature of the dense regions of the ionosphere. As can be seen from Fig. 2, the theoretical curves give satisfactory agreement with almost all the experimental data, except for Drake’ s points at 21 and 40 cm, which were discussed above.

In conclusion it is necessary to note that in the present work emphasis has been placed on those materials which, in the author' s opinion, indicate the presence of a dense ionosphere at Venus. At the same time, however, there remain some data which so far cannot be interpreted from the ionospheric point of view, or even contradict the ionospheric hypothesis. Such data include, for example: Carpenter' s conclusion (^{17}) that the absorption of waves with $\lambda = 12.5$ cm in the atmosphere of Venus is small; the result of radar observations of Venus at a wavelength of 3.75 cm, giving a low (0.9%) value of the reflection cross section at this wavelength; the results of the latest experiments by A. D. Kuzmin, etc. It is possible, however, that these data, if reliable, testify only to the fact that the scheme of the ionosphere of Venus is more complicated than that considered up to now. In any case, at present the need for a detailed clarification of the possibilities of the ionospheric hypothesis appears still more obvious than at the time of writing the author' s previous paper (^{1}).

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