GLOBAL STRUCTURE OF THE VENUSIAN CLOUD LAYER

E. G. Yanovitskij, J. M. Dlugach

Main Astronomical Observatory, NAS of Ukraine
27 Akademika Zabolotnoho, 03680 Kyiv, Ukraine
e-mail: yan@mao.kiev.ua, dl@mao.kiev.ua

This work is based on the results obtained by the authors with colleagues during a period of more than last ten years and presented in [3–8]. The main objective of this presentation is to summarize these long-term investigations, which have resulted in discovering of *global, horizontal, and regular inhomogeneity of the Venusian cloud layer.*

INTRODUCTION

By now, an approximately four-day revolution of the upper part of the Venusian cloud layer in the near-equatorial zone (superrotation), which was found in the ultraviolet spectral range both from the ground-based [1] and space born measurements, has been studied well. In addition, a 4-day variation in the R "line strength" of the 8689 Å CO_2 absorption band was also observed [11]. Discovery of approximately the same period in variations of different characteristics of the atmosphere observed at the ends of a rather wide wavelength range from 3500 to 9000 Å, suggests that a single mechanism (a superrotation of the upper part of the cloud layer) is responsible for these oscillations. This upper layer is likely showing a global horizontal inhomogeneity. To check this hypothesis, we reviewed the results of numerous measurements of stellar magnitude m of Venus in the visible spectral range [2]. These data were processed using the standard procedure of time-series analysis [3]. A series of 70 measurements separated by approximately equal time interval, which were performed by Danjon in 1943, were found to be the most suitable for the analysis.

The autocorrelation function (Fig. 1a) and power spectrum (Fig. 1b) were calculated. One can see from the figures that the series has a distinct harmonic constituent with a period of about 3.5 days (the peak in the power spectrum corresponding to a period of 3.75 days is statistically significant at a level of 92%).The amplitude of oscillations Δm was found to be $0\overset{m}{.}03 \pm 0\overset{m}{.}01$ [3], that is, the entire range of variation of m is $0\overset{m}{.}06 \pm 0\overset{m}{.}02$.

An analysis of possible causes of the periodic variations in m [3, 4] leads to conclusion that this effect can be explained by the global asymmetry of the upper part of the cloud layer revolving due to superrotation with a period of 4 days (Fig. 2a). The corresponding velocity of zonal wind is 100 m/s. Computations [3] show that if the mean optical thickness of the cloud layer is assumed to be equal to 30, then this value for one Venusian hemisphere will be 1.41 ± 0.16 times greater than that for the opposite one.

By analysing the data of the ground-based measurements of equivalent widths of the R(0) lines for four weak CO_2 absorption bands in the near-infrared region ($\tilde{\lambda}$ = 7820, 7883, 8689, 10627 Å) [10], particular estimates of the mean optical thickness for the corresponding hemispheres of Venus were obtained in [5]. In these computations a model of the Venusian atmosphere given in Fig. 3 was used. The altitude of the lower boundary of the cloud layer was adopted to be constant and equal to ~50 km, according to the data from most of the landers. These optical thicknesses were found to be 34.4 and 24.4. The ratio 1.41 between these values is in good agreement with the above-mentioned independent estimate. The altitudes of the upper boundary of the cloud layers proved to be equal to 75.8 and 68.4 for the opposite hemispheres.

Thus, all the available results of observations confirm the existence of a global horizontal regular inhomogeneity of the Venusian cloud layer. Note that this phenomenon could not be found before from the majority of space experiments performed because of their local character, while the ground-based observations enable one to study the planet as a whole and reveal its global characteristics.

We believe that the existence of the global regular horizontal inhomogeneity of the Venusian cloud layer can shed light on such a puzzling, in many respects, phenomenon as superrotation. According to the data on distribution of wind velocity in the Venusian atmosphere with height, this velocity is of about 100 m/s near the upper boundary of the cloud layer and approaches zero near the planet's surface. However, the atmosphere is not rotating as a solid body. As a consequence, sooner or later the interior friction of the atmospheric layers would terminate the superrotation (or, at least, make the motion of atmospheric layers irregular). As far as we know, the mechanism of this regular phenomenon has not been established precisely by now.

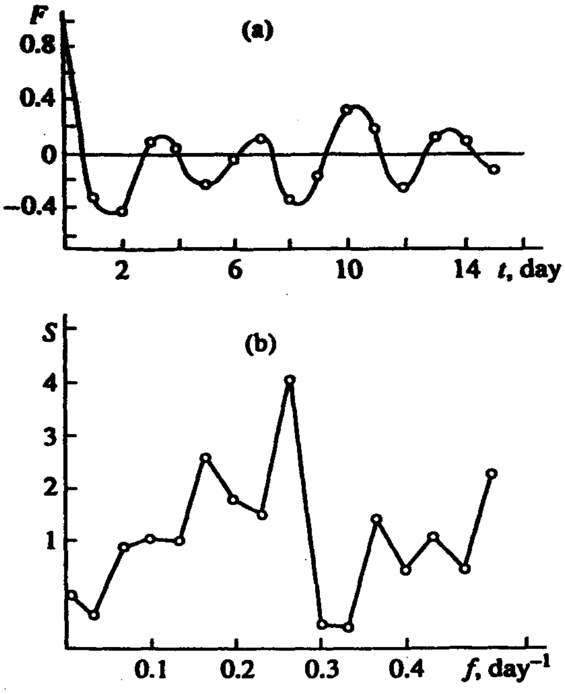

Figure 1: (a) Autocorrelation function and (b) power spectrum of the time series representing the variation in stellar magnitude of Venus

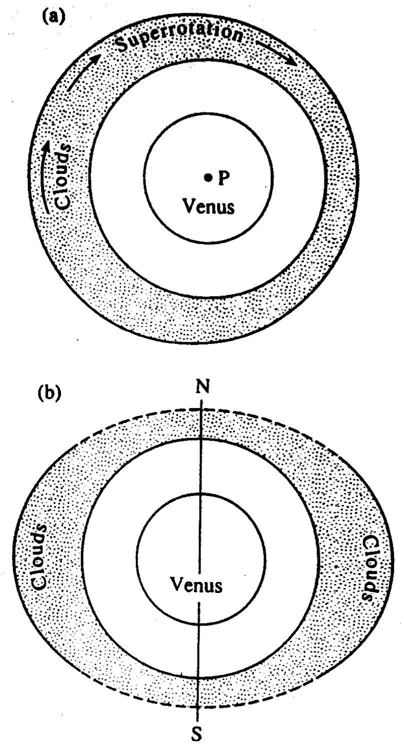

Figure 2: Schematic view of the structure of the Venusian cloud layer: (a) projection onto the equatorial plane and (b) projection onto the plane of the sky

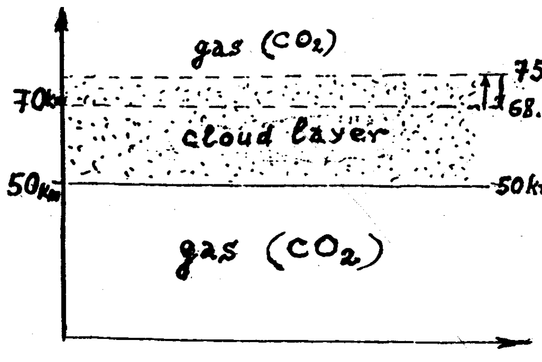

Figure 3: The applied model of the Venusian atmosphere

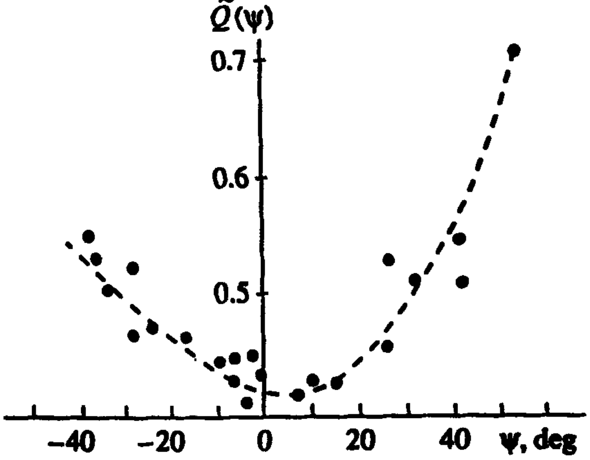

Figure 4: Distribution with latitude ψ of the observed values (dots) of the quantity $\tilde{Q}(\psi)$ for the 7820 Å CO_2 absorption band. Dashed line represents the result of fitting

We think that it is asymmetry of the cloud layer that offers a macroscopic explanation of this phenomenon. Indeed, since the mean optical thickness of an atmosphere over a planetary hemisphere oscillates with a period of about 4 days, its reflectivity (or stellar magnitude) and, consequently, the amount of light energy absorbed in visible and transformed into heat should also oscillate with the same period. On the one hand, this absorbed energy supports the superrotation. On the other hand, the periodic variation of the absorbed energy acts as a peculiar "anchor mechanism" providing this periodicity.

GLOBAL STRUCTURE OF THE CLOUD LAYER AT DIFFERENT LATITUDES

Young *et al.* [9] studied the behaviour of the R(0) lines for 7820, 7883 and 8689 Å CO_2 absorption bands at a period from September 17 to October 7, 1972. The observations were carried out almost daily (only three days were skipped). As it is mentioned above, these observations revealed an approximately four-day periodicity in the variation of the so-called relative R "line strength".

In this work not only the R "line strengths" were given for all the above absorption bands, but also, in the majority of cases, the positions of the spectrograph slit with the respect to the intensity equator or central meridian of the planet were described. This allowed us to study in [6], at least qualitatively, variations of global optical characteristics of the Venusian atmosphere both with latitude ψ and longitude ω.

As an example Fig. 4 shows the $\tilde{Q}(\psi)$ dependence for the absorption band 7820 Å (points). The dashed line in Fig. 4 represents the result of fitting. The quantity $\tilde{Q}(\psi) \sim R(\psi) \sim W(\psi)$, where $W(\psi)$ is the equivalent line width. Analogous curves were plotted for two other absorption bands. The obtained dependences [6] show that, at least up to the latitude $\psi = \pm 50°$, the value of $\tilde{Q}(\psi)$, and therefore $W(\psi)$, increases with increasing $|\psi|$, and that the optical properties of the atmosphere are highly symmetric with respect to the intensity equator.

On the other hand, the equivalent line width W decreases with increasing the optical thickness of the cloud layer [5]. There is a simple physical explanation for this effect: the cloud layer acts as a shield hindering the penetration of photons into the subcloud layer, where photons are mainly absorbed owing to the high abundance of CO_2. Thus, the curve in Fig. 4 indicates that the optical thickness of the Venusian cloud layer decreases essentially from the equator to poles. So, the structure of this layer observed from the Earth can be schematically shown in Fig. 2b.

The latitude structure of the cloud layer shown in Fig. 2b can be easily explained from thermodynamic standpoint. It is well known that the deep layers of the Venusian atmosphere are in local thermodynamic equilibrium. To keep this equilibrium, the "heat machine" of the atmosphere should rearrange the cloud layer to decrease the incoming radiation energy in the deep layers in near-equatorial zone, where the insolation of the upper layer is maximal.

Finally, a *quantitative* analysis of the R "line strength" and equivalent width W of the R(0) line in the CO_2 absorption bands at 7820 and 8680 Å was performed in [8]. It was based on the data obtained in 1972 and published in [9]. All the observations were preliminary *approximately* reduced to a wavelength of 7820 Å and then to the spectrograph slit position along the intensity equator of Venus. As well as above, we considered a two-layer model of the atmosphere (Fig. 3). The equivalent width W of the R(0) line in the CO_2 absorption band at 7820 Å was calculated for this model by the invariant imbedding method. The calculations were made for the spectrograph slit position along the intensity equator, the phase angle $\alpha = 70°$, the optical thickness τ_0 ranging from 20 to 45, two values of the single scattering albedo λ in the continuum (1 and 0.9997), and two heights $h_{\rm cl}$ of the upper boundary of the cloud layer (68 and 75 km). Our calculations confirm a nearly 4-day period of oscillations in the equivalent width and hence in the mean optical thickness of the cloud layer. The average peak-to-peak amplitude is proved to be equal 3-4, and its maximum value in the course of observations was about 7, which corresponded to the variation of $h_{\rm cl}$ from 75 to 70 km. The mean optical thickness of the cloud layer was found to vary with latitude from 37 (at the intensity equator) to 25 (at $\psi = 50°$), and this corresponded to the variation of $h_{\rm cl}$ from 75 to 67 km.

So, we obtained a qualitative confirmation and quantitative estimations of the global structure of the Venusian cloud layer. Result is represented schematically in Fig. 2. However, an important problem remains unsolved: what microscopic mechanism is responsible for the permanent spatial rearrangement of the cloud layer? The solution of this problem is likely to be found at the joint of such sciences as kinetics, dynamics, and thermodynamics of the atmosphere, and this would be done in future.

REFERENCES

[1] *Boyer C. H., Camichel H.* Observations photographiques de la planete Venus // Ann. Astrophys.–1961.–**24**.–P. 531–535.

[2] *Danjon M. A.* Photometrie et Colorimetrie des lanetes Mercure et Venus // Bull. Astronom. Publ. pour L'Observatoire de Paris.–1949.–**14**.–P. 315–345.

[3] *Klimenko V. M., Fomin N. N., Yanovitskij E. G.* Global variations of the optical thickness of the Venus atmosphere. I. Analysis of observations of the integrated brightness // Kinematics and Physics of Celestial Bodies.–1989.–**5**.–P. 33–38.

[4] *Fomin N. N., Yanovitskij E. G.* Global variations of the optical thickness of the cloudy layer of Venus. II. Analysis of equivalent widths of CO_2 lines // Kinematics and Physics of Celestial Bodies.–1990.–**6**.–P. 10–18.

[5] *Fomin N. N., Yanovitskij E. G.* Global variations of the optical thickness of the cloudy layer of Venus. III. Analysis of the behavior of equivalent widths of CO_2 lines for the model of the nonuniform atmosphere // Kinematics and Physics of Celestial Bodies.–1993.–**9**.–P. 30–42.

[6] *Yanovitskij E. G., Dlugach J. M.* On the effect of the width and orientation of the spectrograph slit on the observable spectrum of Venus // Kinematics and Physics of Celestial Bodies.–1995.–**11**.–P. 20–35.

[7] *Yanovitskij E. G.* Global horizontal regular inhomogeneity of the Venusian cloudy layer: a macroscopic analysis of causes of this phenomenon // Solar System Res.–1999.–**33**.–P. 452–455.

[8] *Yanovitskij E. G., Dlugach J. M.* Global horizontal regular inhomogeneity of the Venusian cloud layer: a numerical analysis of the 1972 spectroscopic observations // Kinematics and Physics of Celestial Bodies.–1999.–**15**.–P. 291–303.

[9] *Young A. T., Woszczyk A., Young L. G.* Spectroscopic observations of spatial and temporal variations on Venus // Acta Astron.–1974.–**24**.–P. 55–68.

[10] *Young L. D. G.* High resolution spectra of Venus – A review // Icarus.–1972.–**17**.–P. 632–658.

[11] *Young L. G., Young A. T., Young J. W., Bergstralh J. T.* The planet Venus: a new periodic spectrum variable // Astrophys. J. Lett.–1973.–**181**.–P. L5–L8.