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PRELIMINARY RESULTS OF THE VEGA 1 AND VEGA 2 OPTICAL INVESTIGATION OF AEROSOL IN THE ATMOSPHERE OF VENUS AT 30-60 KM

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Translation of "Predvaritel'nyye rezul'taty opticheskikh issledovaniy aerozol'noy sredy v atmosfere Venery na vysotakh 30-60 km s pomoshch'yu AMS 'Vega-1' i 'Vega-2'," Pis'ma v AZh, Vol. 12, No. 1, 1986, pp. 85-93.

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16. Abstract
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Aerosol particle concentration profiles were measured by an aerosol spectrometer above the landing sites of the Vega 1 and Vega 2 landers. Approximately the same altitude zones were found as in previous experiments: a three-layered basic cloud cover, an intermediate zone, and subcloud haze. There were significant quantitative differences in the concentrations of particles, however, and especially in the spectra of their dimensions. Nightglow was found in the troposphere of Venus at a wavelength of about 1 μm. The backscatter coefficient and the extinction coefficient change very little between 63 and 32 km. Large numbers of submicron particles apparently exist in the atmosphere above the landing sites. /85*

Mounted aboard the Vega 1 and Vega 2 landers were ISAV-A instruments, identical in construction, designed for studying the cloud aerosols of Venus, and specifically for determining along the descent trajectory the numerical concentration of aerosol particles, the dimensional spectrum and index of refraction, and also for assessing their shapes and measuring the backscatter coefficient. The dimensional spectrum of the particles in the clouds of Venus had been directly determined only once, on the Pioneer Venus large probe [Knollenberg and Hunten, 1980].

1. Measurement procedure. The instruments used for the measurements consist of two functional units: an aerosol photoelectric spectrometer and a backscatter detector. Operation of the aerosol spectrometer is based on measurement of the fluxes of light scattered in four directions by aerosol particles passing through the instrument. The backscatter detector measures the light scattered by some region

*Numbers in the margin indicate pagination in the foreign text.

of the aerosol medium near the instrument and/or the atmospheric glow. /86
A diagram of the instrument is shown in Fig. 1. Light from a 5W incandescent halogen lamp 1 is aimed by mirror system 2 at a so-called count space, i.e., a region of space in which the scattering of light by an aerosol particle is measured. The volume of the count space is about 1 mm^3. Some of the scattered light, moving forward, backward, and to the side (the corresponding scattering angles are 7°-17°, 165°-175°, and 25°-65°), is picked up by four optoelectronic units 3, 4, 5, and 6, where silicon avalanche photodiodes are used as photodetectors. The two side detectors operate at the same scattering angles, but in different azimuths.

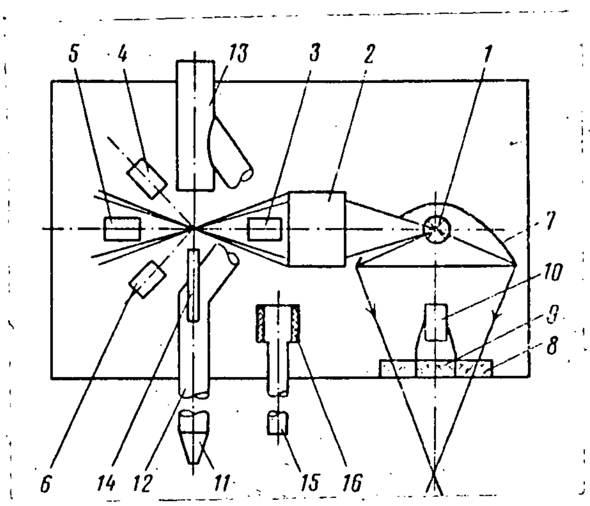

Fig. 1. Diagram of ISAV-A optical aerosol analyzer.

The backscatter detector is located in a common housing with the aerosol spectrometer. Light from lamp 1 is aimed by reflector 7 through window 8 into the free atmosphere. Some of this light, scattered in the atmosphere backward (angles of 160°-175°) through window 9 enters the instrument and is picked up by optoelectronic unit 10. The effective volume of the backscatter detector is 5 cm^3 and the distance between its center and the window is about 3 cm. Lamp 1 is switched off periodically, and at that time the backscatter detector records only the external background radiation, i.e., it operates as a photometer.

The photodetectors and corresponding electronic circuits are located in the sealed part of the detector assembly, which is mounted on the ring frame of the lander, the optical elements in the nonsealed part of this assembly, and the signals are processed in an assembly within the lander.

When particles pass through, logarithms are taken of the impulses generated at the outputs of the four photodiodes of the aerosol spectrometer, and the maximum value of each impulse is recalled and stored in the memory of the instrument before the passage of the next particle. Twice per telemetry frame (0.43 sec) the lander telemetry questions the /87 instrument, each time transmitting to Earth the amplitude of four impulses characterizing the indicatrix of scattering of each separate particle.

The instrument contains a 64-channel pulse-height analyzer, to the input of which arrive, through a logarithmator, all impulses from one of the photodiodes measuring scatter in the lateral direction. The analyzer is designed for determining the spectrum of dimensions of all particles passing through the instrument in an accumulation time of 27 sec. The contents of the analyzer cells are transmitted to Earth with the same period. The impulse amplitude dynamic range of the instrument is 10^4.

Particles are entered into the count space under the effect of an incident flow of gas when the lander descends, using an aspirator (Fig. 1) consisting of coaxially mounted inlet head 11, pointed downward in the direction of descent, feed tube 12, connected to outlet tube 13, and restrictor 14. To create aerodynamic focusing, purified gas from the atmosphere is fed into the instrument through branch pipe 15 and aerosol filter 16. Polystyrene and melamine-formaldehyde resin latexes, 0.5 to 6 μm in diameter, were used in calibrating the aerosol spectrometer. Based on the calibration results, using calculation extrapolation by dimension and index of refraction, relations were constructed between the output signals for all four channels and dimension, and for the backscatter channel also for index of refraction. The instrument functions found in calibration (measured spectrum of dimensions for monodisperse particles) were sufficiently narrow -- the half-width equals 20% for particles ≥ 0.8 μm.

The measurement error for these dimensions is about 30% and rises sharply with decreasing particle diameter.

The instruments functioned normally from the time the lower hemisphere shot off (H = 63 km) to 30 km (Vega 1) and 32 km (Vega 2) for 20 and 18 min, respectively. In this time 43 and 38 dimension spectra and indicatrix of scattering values were transmitted for approximately 5000 particles.

The results obtained in the initial stage of analyzing these data are given below.

2. Numerical concentration of particles. Figure 2 shows the profiles of the numerical concentration of particles, obtained from pulse-height analyzer data for both probes. We can distinguish several characteristic zones that were observed in the previous experiments as well [Ragent and Blamont, 1980; Knollenberg and Hunten, 1980; Marov et al., 1976, 1979, 1983]: D -- a zone of high concentration of particles, above 55 km, C -- a zone of low concentration of particles, in the 51-55-km interval, B -- a zone of high concentration of particles, below 51 km, F -- "subcloud haze," A -- an intermediate zone between zones B and F.

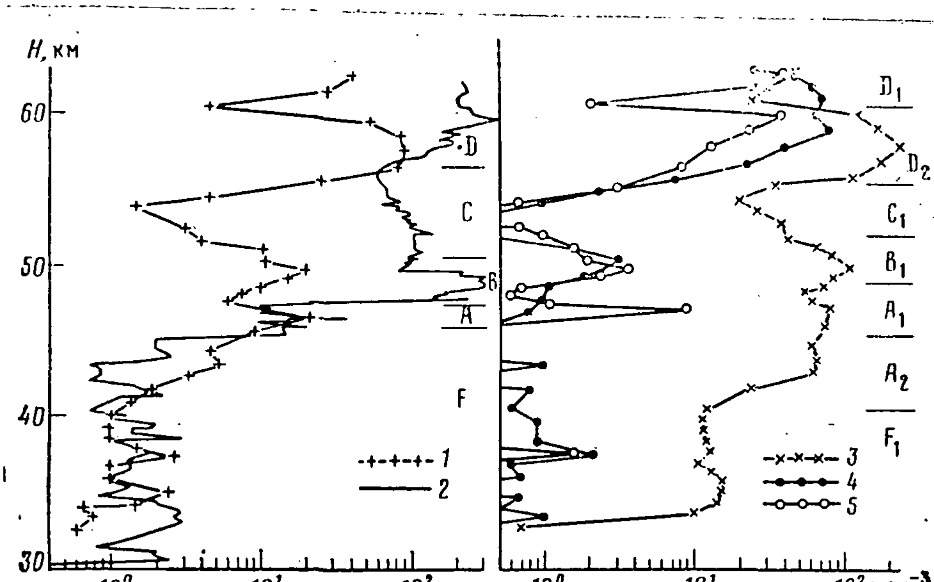

Fig. 2. Profiles of numerical concentration of aerosol particles in the atmosphere of Venus, according to data from spacecraft: 1 -- Vega 2, all particles of diameter D $\geq$ 0.7 μm; 2 -- Pioneer Venus, D $\gtrsim$ 0.6 μm [Knollenberg and Hunten, 1980], 3 -- Vega 2, D $\gtrsim$ 0.4 μm; 4 -- Vega 1, D $\gtrsim$ 1.5 μm; 5 -- Vega 2, D $\gtrsim$ 1.5 m.

The boundaries and dimensions of these zones changed somewhat (especially the dimensions of zone A). Given on the left are the boundaries of the zones according to Knollenberg and Hunten, on the right according to data from our experiment. To emphasize the differences, in the latter case we added numerical subscripts to the letter designations. Averaged dimensional spectra were determined for each zone A_1, B_1, etc. /88

An altitude of about 48 km is usually distinguished as the abrupt lower boundary of the basic cloud layer. Figure 2 shows that the nature of this boundary depends heavily on the dimensions of the particles used to construct the profile.

The concentration profile of particles of diameter $D \gtrsim 0.4$ µm has an elongated intermediate zone, A_1, with relatively smooth decrease of concentration, and if we omit the larger particles ($D \gtrsim 1.5$ µm), the intermediate zone is either substantially narrower, and the concentration at its lower boundary changes much more sharply (Vega 2), or it is not seen at all and almost blends into zone F.

Shown in Fig. 3 as an example are distributions found for zones D_2 and C_1. The distribution for zone D_2 can be represented in the first approximation by

$$n = \text{const}\, D^{-4}, \tag{1}$$

where D is the particle diameter.

On Vega 1 a similar distribution was obtained also for zone C_1, but on Vega 2 a secondary maximum appeared in the 2.5-4-µm interval, i.e., a distribution apparently bimodal. Note that in zone B_1 the spectrum also shows superimposure of a separate mode of relatively large particles on the type (1) distribution. This corresponds, in part, to the pattern found by the Pioneer Venus large probe [Knollenberg and Hunten, 1980], but there also are significant differences. Recall that three modes were distinguished in that work: the first with a spectrum close to (1), the second with a maximum of about /89

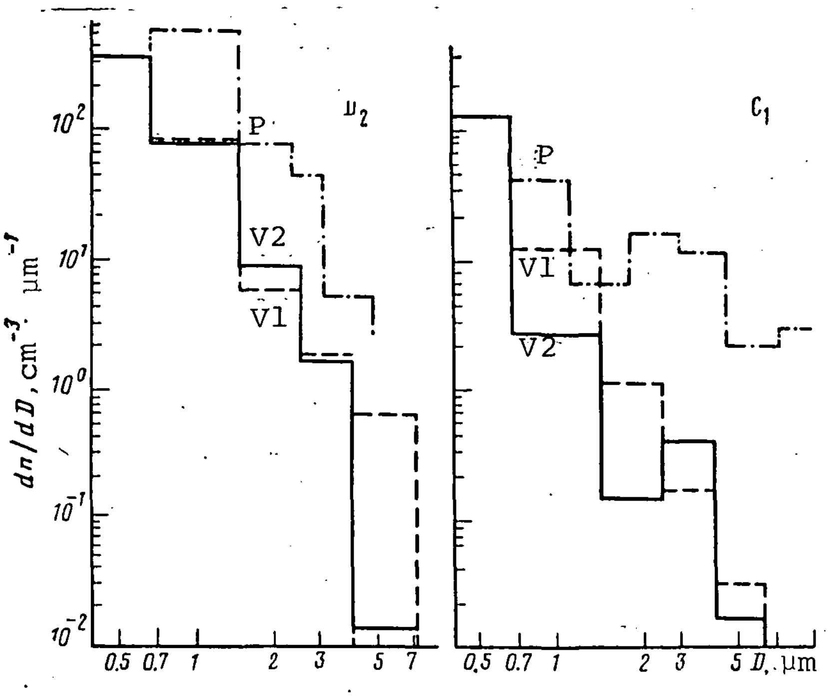

Fig. 3. Examples of averaged particle dimension spectra. Solid line -- Vega 2, zones C_1 and D_2; broken line -- Vega 1, the same zones; line broken with dots -- Pioneer Venus, zones C and D. (Altitude boundaries of the zones same as in Fig. 2).

2.5-3 μm, and the third in the 48-58-km altitude range, with a maximum of about 7 μm.

In contrast to these results, in our measurements large particles with diameters of 5-15 μm were detected only in zone D_1. Furthermore, for us the total numerical concentration of particles exceeding some given diameter in zones B, C, and D is lower.

In our spectra mode 2 is much less obvious, and mode 3 in zones C and B is not seen at all. Two explanations are possible: a) an actual difference of dimension spectrum in different regions of the planet; b) aerodynamic separation of large particles in the instrument, leading to a reduction of their relative concentration within the instrument, relative to free space. Calculation of the aerodynamic characteristics reveals that the effect should be the opposite, i.e., it should lead to increase in the relative concentration of large particles. An appropriate calculation correction -- a coefficient varying approximately from 1.1 to 4, depending on altitude and particle size -- was introduced into our results. Model experiments are now under way to make more precise the scaling factor to free space, after completion of which the results will be corrected, if necessary. /90

Numerical concentrations and the general structure of the profile for particles over 0.4 μm in diameter, obtained in an independent particle-count experiment on Vega 1 and Vega 2 using an LSA instrument, agree roughly with our results.

3. Shape of particles and their index of refraction. Analysis of light scattering by individual particles in three directions allows evaluating the shape of the particles and determining their index of refraction. With passage of a spherical particle, the signals in both lateral channels would be the same. If the shape of the particles differs greatly from spherical, the relationship of the signals would depend on the orientation of the particles and would vary from particle to particle. In the case of spherical particles, the index of refraction can be found from the relationship of signals in the backscatter channel (strong dependence on index of refraction) and in any of the lateral channels (dependence on index of refraction practically absent).

For particles over 1 μm in diameter the ratio of the signals in the two lateral channels is close to unity, so these particles are spherical. The ratio of these signals differs substantially from unity when particle dimensions are reduced. The index of refraction found for particles over 1 μm was equal to 1.4 ± 0.1.

4. Backscatter coefficient. Figure 4a shows the relationship between the backscatter coefficient σ_{170} and altitude, as measured on both landers by backscatter detector. The zonal structure of the altitude distribution is significantly less pronounced here than in the profiles of numerical concentration, although some traces of it are marked.

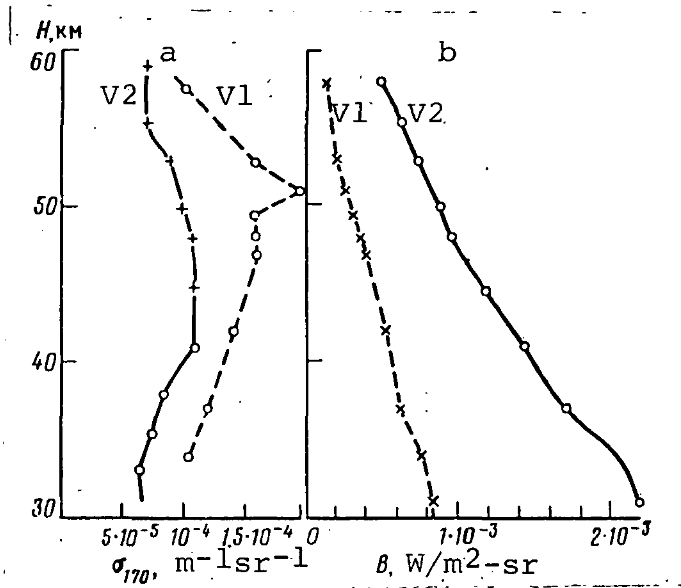

Fig. 4. Results of measurements made with a backscatter detector: a -- backscatter coefficient σ_{170}; b -- intensity of troposphere nightglow B. Broken line -- Vega 1, solid line -- Vega 2.

The high values of σ_{170} in zone F are surprising. Two working hypotheses were examined to explain this circumstance: scattering by very small particles (D ≃ 0.1-0.3 μm) outside the sensitivity limits of the spectrometer, and by very large particles (D ≃ 0.1-1 mm). The first hypothesis demands a concentration on the order of 10^5 cm^{-3} with an index of refraction m ≃ 1.5 and 10^4 cm^{-3} with m $\geqq$ 2.

The very-large-particles hypothesis leads to an unacceptably large mass density of the aerosol medium at D ≃ 1 mm, and with D ≃ 0.1 mm the necessary concentration is too large (∿0.1 cm^{-3}), and such particles should be detected by a spectrometer, unless it is assumed that the collection device filtered them out.

5. Tropospheric nightglow. When the light source of the backscatter detector was switched off, a rather significant flux of radiation was recorded from below the atmosphere of Venus, despite /91 the fact that the experiment was performed in the dead of night (the dip of the Sun below the horizon was 79.3° and 74.0°, respectively, on Vega 1 and Vega 2). The amount of this flux increased with the vehicle's descent.

It is most likely that the background source is heat radiation from the surface, penetrating down through the atmospheric "window" at a wavelength of about 1 μm. The presence of this window was indicated in our previous experiments [Ekonomov et al., 1979; Moshkin et al., 1983]. Figure 4b shows the altitude course of background radiation brightness. The absolute values of background radiation brightness were determined by the backscatter detector with a precision to a factor on the order of 3. Note that the nightglow of the Venus troposphere recently detected in observations from Earth [Allen and Crawford, 1984] in the $\lambda \sim 2$-μm spectral region apparently has a similar origin -- it is most likely heat radiation of the surface and lower atmosphere "seeping" into the corresponding spectral windows. A glow in the about-1-μm region was also observed with the optical sensors on the Vega 1 and Vega 2 balloon probes.

Measurements made earlier in the daytime reveal that true absorption within the "window" at altitudes H > 35 km can be ignored, and the attenuation of the radiation from below is produced here chiefly by scattering. In this case a one-dimensional-medium approxi- /92 mation [Sobolev, 1956] provides a simple relation between the derivative of brightness by altitude, dB/dH, and the extinction coefficient:

$$\sigma_{4\pi} = -\frac{dB}{dH}\frac{2+\tau_0}{B_0}, \qquad (2)$$

where B_0 is the brightness of the source, τ_0 is the total optical thickness of the scattering medium. If we take the effective (i.e., referred to isotropic scattering) optical thickness of Venus' atmosphere at wavelength 1 μm as $\tau_0 = 10$, then $\sigma_{4\pi} = 10^{-4}\ m^{-1}$. To coordinate the values of $\sigma_{4\pi}$ and σ_{170} (their ratio should be $\sim$10), it must be assumed that either the brightnesses were, in fact, an order larger, or during the measurement period there was significant true absorption at altitudes H < 30 km, giving a additional attentuation factor of $\sim$10.

Setting aside the question of the reasons for this discrepancy, we note that a significant contribution from true absorption at altitudes H $\gtrsim$ 30 km seems unlikely, and the smooth nature of the brightness change with altitudes over 45 km can be viewed as an independent argument for high optical density of the subcloud haze.

Recall that, in the history of research on the atmosphere of Venus, one other case was recorded where high extinction coefficients were observed in zones A and F, and it was during the very first experiment measuring illumination on the Venera 8 in 1972 [Avduyevskiy et al., 1973). For several years after these measurements it was thought that the lower boundary of the basic cloud layer lay at the 35-km level. These measurements were conducted near the sunrise terminator.

These Vega 1, Vega 2, and Venera 1 measurement data permit the suggestion that with large angles of solar descent (at night and in twilight) increased density of subcloud haze may be a frequent phenomenon. In addition, two nighttime nephelometer profiles obtained by the Pioneer large probes [Ragent and Blamont, 1980] indicate a low density of subcloud haze, just as in all daytime measurements (there were eight in all). Under night and twilight conditions there apparently is an increased tendency towards variability of subcloud haze characteristics. Separate layers of higher concentrations of particles, located at relatively low altitudes, were also observed in the daytime by Veneras 9 and 10 [Marov et al., 1976] and Venera 11 [Marov et al., 1979].

6. Conclusions. 1) The vertical structure of the particle concentration profile at the landing sites of Vega 1 and Vega 2 can be qualitatively described by the same ideas about altitude zones as obtained for the day side of the planet: a "three-layer" basic cloud layer, an intermediate zone, and a subcloud haze with lower boundaries at altitudes of approximately 45-48, 42-45, and 32-35 km.

2) Concentrations of particles with diameters in the 0.7-10-μm range above 45 km, and particularly the relative content of larger particles in this range, are lower than at the landing site of the Pioneer large probe. /93

3) Particles of diameter D > 1 μm are spherical and have indices of refraction of 1.4 ± 0.1.

4) At altitudes of 63-30 km, a nightglow was detected in the troposphere of Venus at a wavelength of about 1 μm, its source probably being the hot surface of the planet.

5) The backscatter and extinction coefficients vary little throughout the entire region of altitudes from 63 to 32 km that the measurements encompassed, and display almost no vertical structure corresponding to the concentration profile.

6) The results formulated in paragraphs 1, 2, and 5 are evidence of the presence in the atmosphere above the landing sites of submicron particles with a high numerical concentration ($\sim 10^4$ cm^{-3}).

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