Detection of dust particles in the coma of Halley's Comet by the Foton detector

S. I. Anisimov, V. P. Karyagin, V. A. Kudryashov, Yu. A. Osip'yan, Yu. A. Ryzhov, S. B. Svirshchevskiĭ, A. Z. Strukov, A. V. Terterashvili, V. E. Fortov, I. M. Khalatnikov, and A. E. Sheĭndlin

S. Ordzhonikidze Moscow Aviation Institute; L. D. Landau Institute of Theoretical Physics, Academy of Sciences of the USSR; Institute of Solid State Physics, Academy of Sciences of the USSR; Institute of Cosmic Studies, Academy of Sciences of the USSR; Institute of High-Temperature Physics, Academy of Sciences of the USSR

(Submitted 17 October 1986)
Pis'ma Zh. Eksp. Teor. Fiz. **44**, No. 10, 477–480 (25 November 1986)

The first results of direct measurements of the characteristics of dust particles with mass $m > 10^{-9}$ g by the Foton detector, carried on the VEGA 1 and VEGA 2 space vehicles, are reported. The nature of the changes in the dust flux along the trajectory of the space probe is reported. The mass distribution of the dust particles is also reported.

To study the dust environment of Halley's Comet was one of the basic purposes of the VEGA project. This study was carried out by a battery of scientific instruments which permitted measurements over a broad range of the mass of the dust particles.[1] The Foton detector detected comparatively large dust particles (with masses greater than $\sim 10^{-9}$ g) and studied their interaction with elements of the dust shield of the space vehicle. This instrument consists of a detection chamber with a thin nickel screen, containing optical and acoustic sensors, and an electronic unit for processing the signals and transferring them to the telemetry apparatus.[1,2] The dust particles struck the screen at an angle of 60° from its surface.

The diagnostic study of the dust particles is based on an optical method for measuring the area of the holes punctured in the screen by the particles. For this purpose, the flux of solar radiation which passes through these holes to a photometric system of the instrument is detected. For more comprehensive and more reliable information on the properties of the dust particles and on the processes by which the protective shields are damaged in the high-velocity collisions, the instrument also measures the amplitude and duration of the light flash that occurs when a target 0.1 mm thick is punctured. The instrument also measures the momentum transferred to the shield. The instrument was calibrated both by means of direct measurements and through the use of the results of a laser modeling of high-velocity impact and numerical calculations on the interaction of dust particles with shields.

The mass of the lightest dust particle which penetrated the shield was 6×10^{-10} g. Particles in this range are detected by the instrument only in the flash channel and the acoustic channel, because of the particular features of the orientation of the shield with respect to the flux of solar radiation. In the present letter we discuss the results for only that group of particles for which all three characteristics of the interaction of the particles with the shield were measured: the energy of the flash, the momentum trans-

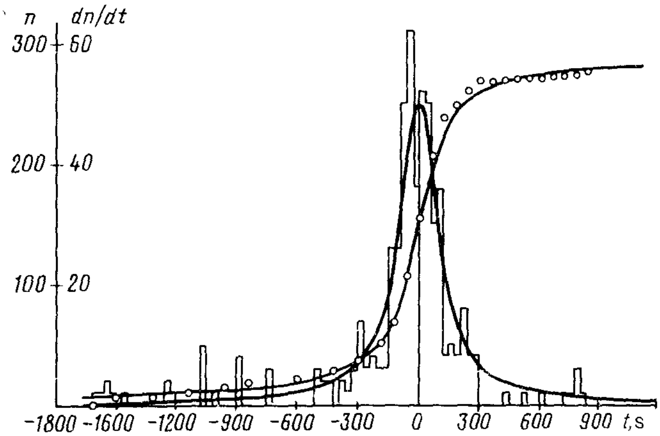

FIG. 1

fer, and the size of the hole. In the VEGA 1 experiment, the number of such particles detected was $n_0 = 275$. A minimum hole area, 2.2×10^{-4} cm^2, is produced by particles of mass 6×10^{-9} g. The total area of the punctures amounts to 0.25% of the working area of the shield (137 cm^2).

Figure 1 shows the time evolution of the flux of dust particles incident on the shield (a summation was carried out over 30-s time intervals). The value $t = 0$ determines the reference point of the time scale: the point of closest approach of the vehicle to the nucleus of the comet. There are significant fluctuations in the flux of particles, but the total number of particles detected by the time t, i.e., $N(t)$, can be approximated well by the expression

$$N(t) = \frac{n_0}{2}\left[1 + \frac{2}{\pi}\arctan\left(\frac{Vt}{R_m}\right)\right], \tag{1}$$

where V is the velocity of the vehicle with respect to the dust cloud (79.27 km/s for VEGA 1), and R_m is the minimum distance from the nucleus (8879 km for VEGA 1). The agreement between (1) and the experimental results (the points in the figure) indicates that the mean particle density in the dust environment falls off as R^{-2} with distance from the nucleus of the comet. Comparison of the mean dust flux striking the shield [found by differentiating (1) and also shown in Fig. 1] with the measured flux reveals a region with an elevated density of dust particles near the point of closest approach to the nucleus. The probable reason for this behavior is the occurrence of intense local ejections of gas and dust from the surface of the nucleus ("jets"), which were also detected by other instruments.[3,4]

During the fly-by of VEGA 2, both the total amount of dust and the fluctuations in the particle flux density were smaller. Analysis of the results reveals that the mean dust density along the trajectory was 1.5–2 times lower than that for VEGA 1.

From these measurements we can find the mass distribution of the dust particles. Using Ref. 5, we can write

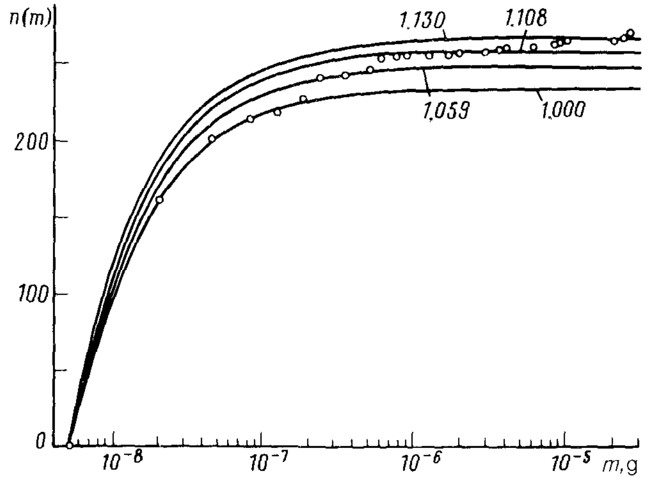

FIG. 2

$$n(m_1, m_2) = C(m_1^{-\alpha} - m_2^{-\alpha}), \tag{2}$$

where $n(m_1, m_2)$ is the number of particles in mass range $m_1 < m < m_2$ which are incident on the shield of the instrument. A direct analysis of the experimental data yields the value $\alpha \approx 0.58$, which is noticeably different from that which follows from astronomical observations[5]: $\alpha \approx 1$. This discrepancy can be understood by noting that the time interval between the emission of a dust particle and its detection in the VEGA experiment was comparable to the time scale of the changes in the activity of the comet. After the comet passed perihelion, its activity fell off over time. Since the heavy particles move more slowly and are delayed to a greater extent, the distribution observed experimentally should have an excess of heavy particles. This excess would be manifested as a decrease in the effective exponent α. The simplest way to find the distribution of particles emitted by the nucleus is to work from data on the group of the lightest particles, for which the delay effect is minimized. For the mass interval $m < 10^{-7}$ g we then find the exponent $\alpha \simeq 0.86$, which is close to the result of Ref. 5. The corresponding distribution is shown in Fig. 2. These curves correspond to different values of the constant C in expression (2). In accordance with the discussion above, the data on the heavier particles fall on the curves with the larger values of C. According to the Giotto data,[6] the exponent near the nucleus of the comet is $\alpha \approx 0.83$, while that at a distance of 2200 km is $\alpha \approx 0.66$.

The differential mass distribution of the dust particles in the interval $10^{-9} < m < 10^{-5}$ g can be described by

$$dn = Am^{-1,86}\,dm\,, \tag{3}$$

where $A = 1.5 \times 10^{-9}$ cm$^{-2}\cdot$g$^{0.86}$.

The rate of dust production can be estimated as follows with the help of (3):

$$\dot{M} = 4R_m \int_{m_1}^{m_2} mv(m)dn \approx 1.5\times10^7 (m_1^{-0.027} - m_2^{-0.027}), [g/s],$$

where $v(m) = 10^3\rho^{-1/3}m^{-1/6}$ [cm/s] is the velocity of the dust. For the mass interval in which distribution (3) holds we have $\dot{M}\approx 5$ metric tons per second. Since $\dot{M}$ depends very weakly on the integration limits, and at $m < 10^{-9}$ g the number of particles increases comparatively slowly with decreasing mass[7] ($\alpha\sim 0.5$–0.6), the total mass of dust generated per second by the nucleus of the comet probably does not exceed 10 metric tons.

We sincerely thank R. Z. Sagdeev for constant interest in this study and for many stimulating discussions.

[1]Venus-Halley Mission Experiment Description and Scientific Objectives of the International Project VEGA (1984–1986), Louis-Jean, Gap, Paris, 1985, p. 210.

[2]S. I. Anisimov, V. M. Kovtunenko, V. P. Karyagin, *et al.*, Sluzhebno-nauchnyĭ eksperiment "foton" dlya izucheniya mikrometeoritnoĭ atmosfery komety Galleya i kharakteristik ee vzaimodeĭstviya s kosmicheskim apparatom "Vega" (Foton Service-Scientific Experiment for Studying the Micrometeoroid Atmosphere of Halley's Comet and the Characteristics of Its Interaction with the Vega Spacecraft), Preprint No. 2-176, Institute of High-Temperature Physics, Academy of Sciences of the USSR, Moscow, 1985, p. 28.

[3]Z. Sekanina and S. M. Larson, Nature **321**, 357 (1986).

[4]J. A. Simpson, R. Z. Sagdeev, A. J. Tuzzolino, *et al.*, Nature **321**, 278 (1986).

[5]N. Divine, in The Comet Halley Dust and Gas Environment, ESA-SP-174, 1981, p. 25.

[6]J. A. M. McDonnel, W. M. Alexander, W. M. Burton, *et al.*, Nature **321**, 338 (1986).

[7]E. P. Mazets, R. L. Aptekar, *et al.*, Nature **321**, 276 (1986).

Translated by Dave Parsons