NATURE OF DUST GRAINS IN THE ATMOSPHERE OF COMET ASHBROOK

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Abstract. Anomalous polarization at small phase angles is confirmed as a common feature of dusty cometary atmospheres. The opposition effect is detected and interpreted as evidence of similarity between grains covering interplanetary, cometary and asteroidal surfaces. The prevailing radii of dust grains in the comet's atmosphere are estimated to be 0.15-0.19 μm.

OBSERVATIONS

P/Ashbrook 1977g was observed with the 70-cm reflector at the Hissar astronomical observatory during 11 July - 28 November 1978. The polarization observations were unfiltered ($\lambda_{eff} = 524$ nm); their m.s.e. was about 1%. The photometric ones were made in the UBV system with m.s.e. $\sigma_V = \sigma_{B-V} = 0\overset{m}{.}03$ and $\sigma_{U-B} = 0\overset{m}{.}05$. An 88" diameter diaphragm was used throughout all the observations.

Photometric observations are usually represented by the expression $V-5\ \lg\Delta = V_o+2.5\ n\ \lg r$, V_o and n being photometric parameters. In our case the heliocentric distance r changed but little ($\sim$0.1 AU) so the values $n = 7.08\pm3.27$ and $V_o = 5\overset{m}{.}32\pm2\overset{m}{.}97$ turned out to be very uncertain. Instead, the comet brightness $V-V_o-2.5\ n\ \lg r-5\ \lg\Delta$ shows, independently of the value of n, a clear dependence on the phase angle α. In the range $12° \geq \alpha \geq 0°$ the brightness increased by $0\overset{m}{.}6$, i.e. a kind of opposition effect took place, and in the region 19°-25° a brightness enhancement of rainbow type was observed (Figure 1a). These brightness changes seem to be real as no outbursts were noted and good reproducibility was revealed.

The color index B-V (Figure 1b) is typical for comets. With the exception of preperihelion observations, B-V remains constant, suggesting equal input of gaseous emission in both the B and V bands. B-V variation in the starting period could be caused by the contribution of C_3 or CO^+ emissions to the band B. The mean value of $U-B = 0\overset{m}{.}25$ (Figure 1c) shows that the CN emission makes no appreciable contribution to the U band.

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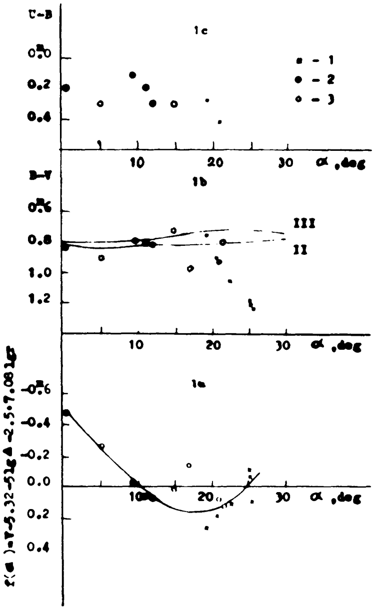

Fig. 1. Dependence of brightness (a) and colors B-V (b) and U-B (c) on the phase angle α: 1- before perihelion and opposition; 2- after perihelion, but before opposition; 3- after opposition. Curves depict the color B-V calculated for models II ($\rho_1 = 0.15\ \mu$; $\rho_2 = 0.03\ \mu$) and III ($\rho_1 = 0.19\ \mu$; $\rho_2 = 0.03\ \mu$).

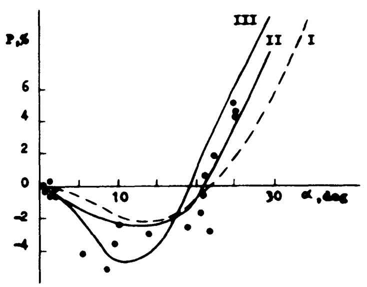

Fig. 2. Dependence of the polarization degree P on the phase angle α for comet Ashbrook 1977g. Curves illustrate the models: I (ρ_1=0.12 μ, $\rho_2 = 0.03\ \mu$), II ($\rho_1 = 0.15\ \mu$, $\rho_2 = 0.03\ \mu$), and III ($\rho_1 = 0.19\ \mu$, $\rho_2 = 0.03\ \mu$).

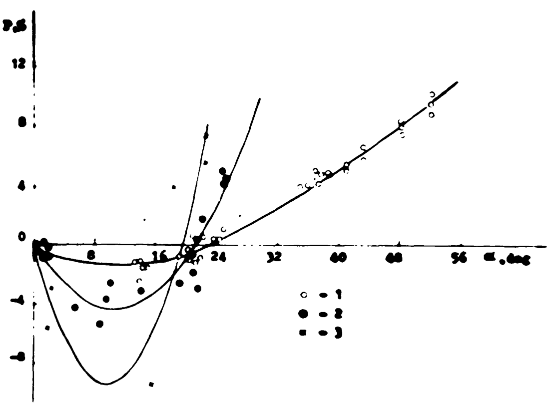

Fig. 3. Dependence of the polarization degree P on the phase angle α for comets: 1- West 1975n, 2- Ashbrook 1977g, 3- Chernykh 1977l.

The 300-550 nm spectrum was a pure reflected solar one (Larson 1978) confirming scattering from dust particles as the main light source of the comet.

The polarization P versus phase angle α dependence for comet 1977g is shown in Figure 2. Figure 3 shows the comparison of P - α dependences for comets Ashbrook 1977g, West 1976 VI (Kiselev and Chernova 1978) and Chernykh 1977l (Kiselev and Chernova, unpublished). Anomalous polarized light was observed also during the postoutburst period in comet Schwassmann-Wachmann 1 (Kiselev and Chernova 1979). Hence, the anomalous (negative) polarization of the cometary dust particle radiation is a general phenomenon at small phase angles $\alpha \leq 20°$.

INTERPRETATION

Comparison with calculations by Janovitsky and Dumansky (1972) or Deirmendjian (1969) shows that the P versus α function for 1977g is in disagreement with any monomodal dust population model. Sufficiently good agreement is obtained from a bimodal particle system (Figure 2) with two different modes of the realtive size $a = 2\pi\rho/\lambda$, corresponding to two different modal values of the grain radius ρ, defined as $\rho_{mod} = a_{mod} \cdot \lambda_{eff}/2\pi$.

The P versus α curves of Figure 2 were calculated for three selected models, containing large particles with modal radii $\rho_1 = 0.12$; 0.15 and 0.19 μ; Rayleigh particles with modal radii $\rho_2 = 0.03$ μ and (for the sake of generality) a gas component. The constant intensity ratio adopted for light scattered by large, Rayleigh and gas particles was 6:1:3. Normal logarithmic size distribution and refraction index $n' = 1.33$ were adopted for both dust populations. Tables by Janovitsky and Dumansky (1972) were used.

Polarization of the gas emission was estimated by Öhman's formula $P_{em} = P_{90} \cdot \sin^2\alpha/(1+P_{90} \cdot \cos^2\alpha)$ where $P_{90} = 0.1$ is the typical polarization degree of the molecular component at $\alpha = 90$. It should be noticed that P_{em} gives only a minor contribution and its neglect would not affect appreciably the calculated grain dimensions.

The color index $B-V = -2.5 \log (X_B/X_V)$, where X_B and X_V are the normalized phase functions, was calculated for our models II and III (Figure 1b) taking into account only the dust components and assuming the gas emission contribution to be equal in both color bands. Good agreement with observations confirms the dusty atmosphere model consisting of grains with 0.15-0.19 μ radii and a minor addition of Rayleigh grains.

Interesting information may be obtained from the steep rise of brightness in the vicinity of zero phase angle. For minor planets this rise begins at $\alpha \lesssim 7°$ (Gehrels 1956); for comet 1977g at $\alpha = 12°$ and for interplanetary dust at $\alpha \lesssim 20°$ (Dumont and Sanchez 1975). So the dust in comet Ashbrook may have physical properties intermediate between those of interplanetary dust and dust covering the asteroidal surfaces.

An appreciable contribution of the phase function to the brightness was also pointed out by A'Hearn et al. (1978) when analyzing the gas and dust production rates in comet 1976e at small α's. According to the properties of spherical or oriented unspherical particles (prevailing forward and backward scattering) the region of small α is the very thing needed for the phase dependence. One may conclude that the observed phase dependence of the brightness of comet Ashbrook at small phase angles is a general property of comets.

If the brightness enhancement at $\alpha \approx 19° - 25°$ is really a rainbow, it may suggest the presence of a number of large grains with $n' \approx 1.5$.

Among the grain groups considered the most important and reliable one is that consisting of large dielectric grains. These grains are responsible for the general appearance of the P - α curve. The Rayleigh particles serve to moderate the negative branch depth and to displace the inversion angle towards $\alpha = 20°$ and the positive branch maximum to $\alpha = 90°$ as cometary observations suggest. But metallic particles could also give an effect of depth decrease (Coffeen 1969). So the different appearance of the P - α relations (Figure 3) could also be caused by different small admixtures of metallic particles.

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