Memoirs of the Faculty of Science, Kyoto University, Series of Physics, Astrophysics, Geophysics and Chemistry, Vol. XXXVII, No. 2, Article 7, 1988

Dust and C_2-Contents in the Coma of HALLEY's Comet (1986III)

By

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(Received Sep. 29, 1987)

Abstract

Photographic observations of Halley's Comet (1986III) were carried out at the Hida Observatory, with use of two interference filters: IF7215 (for red continuum at 7215 Å) and IF5148 (for C_2 emission at 5148 Å). We analyzed the negatives exposed on March 25, 31, April 1, 12, and 13, 1986, and estimated total mass of dust and C_2 molecules of the coma. On March 25 masses of dust and C_2 were 3.3×10^{13} g and 2.2×10^{10} g respectively. Dust and C_2-contents fall off as the comet goes away from the Sun, and they become reducing to 5.1×10^{12} g and 1.3×10^{9} g, respectively, on April 13, 1986.

1. Introduction

We observed Halley's Comet photographically with use of a Ni-Tec image intensifier attached to the Zeiss 65 cm refractor at the Hida Observatory in a period from March 25 to May 25, 1986. We used two filters, *i.e.*, interference filters IF7215 (for red continuum at 7215 Å) and IF5148 (for C_2 emission at 5148 Å), characteristics of which are specified by the IHW (e.g., Edberg, 1983). For red photographs we used a red corrector lens, but sometimes not. The equivalent focal lengths of the optical system are 7.34 m and 8.47 m, and the field of view is $9'.3\phi$ and $8'.1\phi$ for the case of with- and without-red corrector lens, respectively. The characteristics of filters and the equivalent focal lengths are summarized in table 1. The emulsions used are Kodak Tri-X and TP2415 hypersensitized 35 mm films. In order to estimate dust and C_2-contents in the inner coma, we analyzed negatives exposed through IF7215 and IF5148 on March 25, 31, April 1, 12, and 13, 1986.

Table 1. Characteristics of filters and equivalent focal length of the 65cm refractor.

Color	Filter	Peak wavelength	Full width at half maximum	Equivalent focal length	Field of view
Red	IF7215	7215Å	110Å	7.34m	9'.3
Green	IF5148	5148Å	110Å	8.47m	8'.1

2. Stellar Magnitude of Coma

With a microdensitometer we traced negatives in a field range of 3.5×2.7 arcmin^2 centered at the brightest point of the comet. The traced region corresponds to the area of 10×7.8 $(10^4$ km$)^2$ on the comet of March 25, 1986. The photographic density of the negatives is transformed into the intensity scale by using a characteristic curve, which is obtained from the photographic density exposed on the film using a 7-step wedge through the image intensifier and the filters. The bright part of the inner coma is included in the traced range. The fainter limb of the coma of March 25, 31, and April 1 is overcome by the moon light (see Fig. 1).

To estimate the brightness of the coma, we referred to a trail of a star on the same negatives in the case of March 25 and 31, and also a star image of 7–8 mag near the comet, which was exposed just before or after exposure for the comet in the case of April 1, 12, and 13. We represent the observational data in Table 2. The stellar magnitude of the reference star on March 25 was estimated from the dimension of its image on the Palomar-National Geographic Sky Atlas. The central wavelengths of the Palomar Atlas are about 6500 Å and 4000 Å for red and blue images. We adopted the mean of the red and blue magnitude for green at 5148 Å. In our estimation of the magnitude of the reference star on March 25, an error of 0.5 mag may be included. The visual magnitude and spectral type of other reference stars were adopted from the SAO catalogue. The visual magnitude is transformed into red magnitude at 7200 Å by spectral type. Although V-R index of the same spectral type differs for individual stars, we used the mean of the V-R in the same spectral type as that of the reference star. In order to estimate the mean value we referred to "UBVRIJKL photometry of the bright stars" (Johnson et al., 1966). For the magnitude of the reference stars at 5148 Å, we assume that it is equivalent to the visual magnitude. For the estimated stellar magnitude of the reference stars in red and green light, an error of 0.1 mag may be included. Our characteristic curve also contains some amount of errors, which affects the intensity of the reference stars. The estimated error is about 10% in intensity. On the central part of the phospher screen of the photocathode of the image intensifier,

Table 2. Observational data.

Date (1986)	UT (h:m)	Exp.T. (m)	Filter	R.A. (1950.0)	Decl. (1950.0)	r (AU)	Δ (AU)	α (°)
Mar. 25	19 : 25	5.0	Green*	19 14.7	−31 09	1.082	0.666	65
	19 : 54	5.0	Red+	19 14.7	−31 10	1.082	0.666	65
Mar. 31	18 : 20	5.0	Red	18 24.0	−38 27	1.174	0.533	58
Apr. 1	18 : 30	5.0	Green	18 11.5	−39 51	1.190	0.514	56
	18 : 36	5.0	Red	18 11.5	−39 51	1.190	0.514	56
Apr. 12	14 : 58	2.5	Green	14 13.8	−45 35	1.357	0.421	28
	15 : 22	2.5	Red	14 13.4	−45 34	1.357	0.421	28
Apr. 13	14 : 23	5.0	Red	13 50.6	−44 18	1.372	0.427	25
	14 : 31	5.0	Green	13 50.5	−44 18	1.372	0.427	25

* 1 F5148 + 1 F7215

photo-sensitivity is almost uniform, but the sensitivity near the edge of the screen is reduced to 60% of that on the central part. Therefore we corrected the intensity of the reference star for the case of March 25, on which day the star image was located near the edge of the screen. The total error in the brightness of the coma is 0.9 mag for the case of March 25 and 0.3 mag for other days.

Table 3. Stellar magnitude of Halley's Comet (1986).

Date	m_R	$m_{0,R}$	m_G	$m_{0,G}$	m_{C2}	H
Mar.25	3.7	4.3	2.5	3.2	2.7	3.6
Mar.31	5.9	6.7				
Apr. 1	4.8	5.7	4.5	5.4	5.0	6.4
Apr.12	5.0	5.8	5.1	6.0	6.0	7.9
Apr.13	5.2	6.0	4.9	6.0	5.3	7.2

In table 3, we show the stellar magnitude of the coma m_R and m_G and its absolute magnitude $m_{0,R}$ and $m_{0,G}$ defined as

$$m = m_0 + 5.0 \log \Delta + 7.7 \log r$$

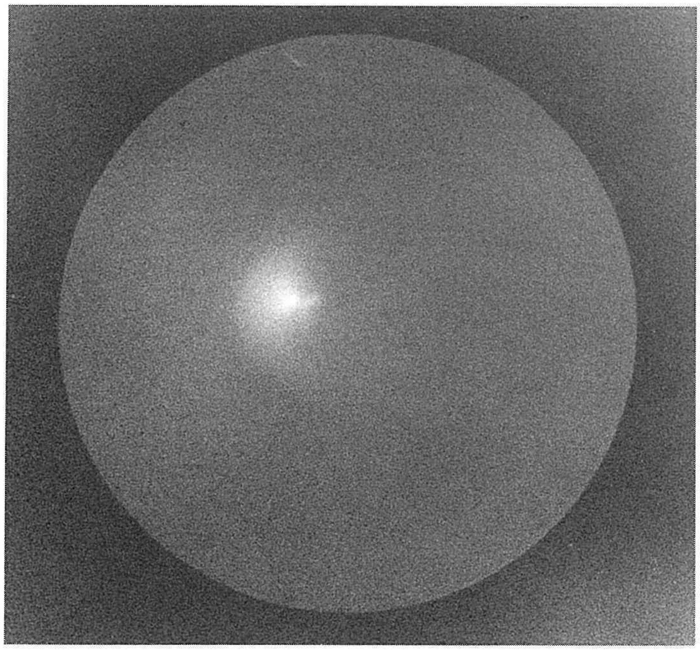
where Δ and r are geocentric and heliocentric distances of the comet, respectively, in AU (Edberg, 1983; Kosai, 1986). Kosai (1986) shows that the light curve of the visual magnitude after perihelion in 1986 has the same inclination as that in the preceding apparition in 1910.

3. Mass of Dust in the Coma

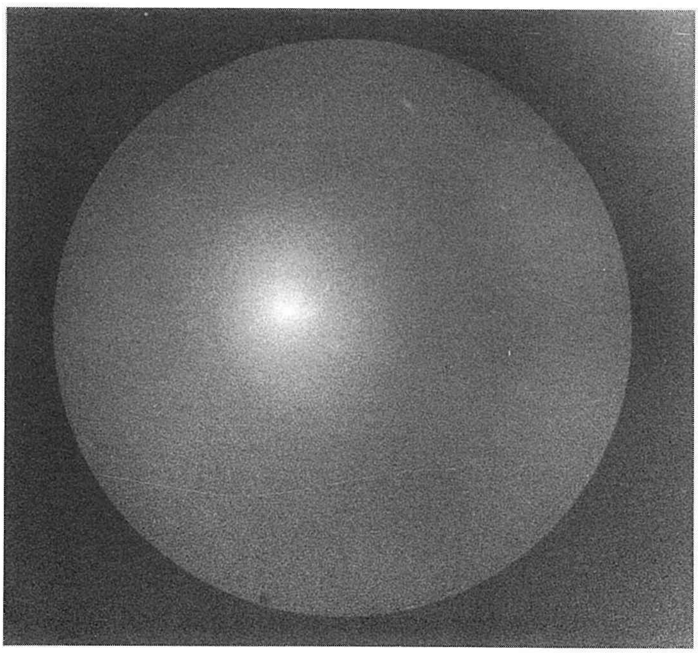
From the stellar magnitude m_R in table 3, mass of dust in the coma is estimated, because the filter IF7215 passes continuum only. In the following discussions we assume that dust particles are spherical. Vega-2 observations suggest that the size distribution of dust is given by a power law (Mazets et al., 1986);

$$n(a) \propto \begin{cases} a^{-2.0} & 3\times10^{-6} < a < 6\times10^{-5} \\ a^{-2.75} & 6\times10^{-6} < a < 6\times10^{-4} \\ a^{-3.4} & 6\times10^{-4} < a \end{cases} \tag{1}$$

where a is the radius of a dust particle in units of cm. Originally, the range of the distribution (1) is given by mass. However we converted it to its size (in radius), assuming that the mass of a dust particle is given by $(4/3)\pi a^3 \rho$, where ρ stands for density. After Lamy et al. (1987), ρ is a function of a as shown in equation (6), and its upper and lower limits are 2.2 and 0.7, respectively. It is reasonable to assume $\rho=1$ in estimate of the range of the size distribution (1). Mukai et al. (1987) estimated the refractive index of the dust particle of Halley's Comet (1986III) from the data of polarimetry. By interpolation of their values, we get refractive index at our wavelengths:



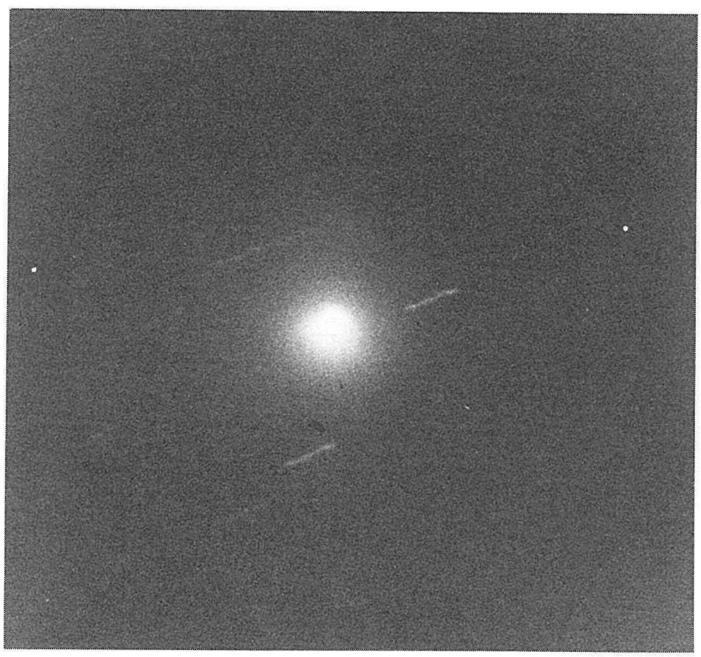
(a) Mar.25, 1986. 19h54.0m U.T. (IF7215).



(b) Mar.25, 1986. 19h31.8m U.T. (IF5148).

Fig. 1. Coma of Halley's Comet.

(c) Apr.13, 1986. 14h22.7m U.T. (IF7215).



(d) Apr.13, 1986. 14h31.0m U.T. (IF5148).

$$n = 1.383 - 0.038i \quad \text{at } \lambda = 7200\text{Å},$$
and
$$n = 1.387 - 0.032i \quad \text{at } \lambda = 5100\text{Å}. \tag{2}$$

On the assumption of Mie scattering, the scattering cross section and the phase function of dust particles are easily calcutated. Fig.2 shows the phase function based on the size distribution (1) and the refractive indices (2). Our observational range of the scattering angle is 115° through 155°. In this range the phase function is minimum.

The number density of dust in the coma may be low, so that single scattering is dominant in the coma. The light from a particle (radius a) observed on the earth is

$$f(a) = \frac{F_{\odot,R}}{\Delta^2 r^2} \frac{\sigma\varphi(\alpha)}{4\pi}, \tag{3}$$

where $F_{\odot,R}$ is the solar flux at the observed wavelength at 1 AU, σ the scattering cross-section, and $\varphi(\alpha)$ the phase function of the particle at phase angle α. The flux F_R from the coma is

$$F_R = \int_{a_1}^{a_2} f(a)n(a)da. \tag{4}$$

On the other hand the flux F_R is obtained from the brightness of the coma.

$$F_R = F_{\odot,R} \times 10^{0.4(m_{\odot,R} - m_R)} \tag{5}$$

where $m_{\odot,R}$ and m_R stand for magnitude of the Sun and the comet at 7200 Å. From equations (4) and (5) the proportional constant of the size distribution (1) is determined. In the calculation we set the lower and upper limits of the distribution as $a_1 = 1.0 \times 10^{-6}$

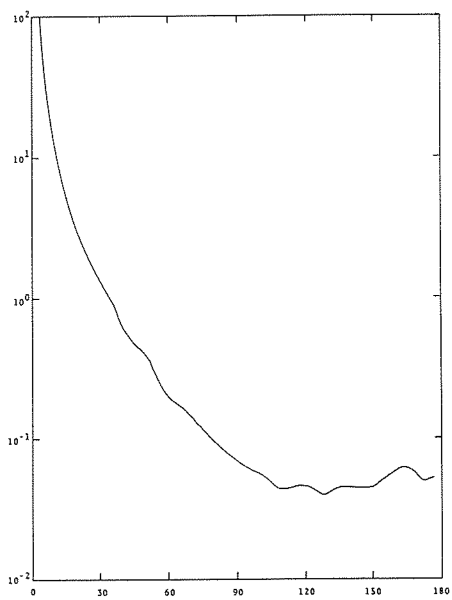


Fig. 2. Phase function of dust of Halley's Comet (1986III) at 7200Å. Abscissa is phase angle in degree.

Table 4. Dust and C_2-contents in the coma.

Date	M_d (g)	M_{C_2} (g)	$\dot{N}_{C_2}^{*}$
Mar. 25	3.3×10^{13}	2.2×10^{10}	1.9×10^{27}
Mar. 31	3.5×10^{12}		
Apr. 1	9.4×10^{12}	2.0×10^{9}	1.4×10^{26}
Apr. 12	6.8×10^{12}	7.0×10^{8}	3.6×10^{25}
Apr. 13	5.1×10^{12}	1.3×10^{9}	6.9×10^{25}

* in units of molecules s^{-1}

cm and $a_2=1.0\times10^{-2}$ cm.

The mass of a dust particle of radius a is estimated from the density ρ which is a function of a (Lamy et al., 1987).

$$\rho = 2.2-1.4\frac{a}{a+1\times10^{-4}}\,, \tag{6}$$

where a is in units of cm. The total mass of dust in the coma is

$$M_d = \int_{a_1}^{a_2}\frac{4}{3}\pi a^3\rho n(a)da\,. \tag{7}$$

In tabel 4, the mass of dust in the coma is represented. It is 3.3×10^{13} g on March 25, 9.4 $\times10^{12}$ g on April 1, and 5.1×10^{12} g on April 13, 1986.

4. Mass of C_2 in the Coma

On the photos exposed through interference filter IF5148, the emission light of C_2 (0–0) band overlays the light scattered by dust particles and by molecules such as H_2O, C_2, and others. However the intensity of scattered light by molecules may be negligible, compared to the emission light of C_2 and the scattered light by dust. Therefore the flux due to C_2 (0–0) band is

$$F_{C_2} = F_G - F_{d,G} \tag{8}$$

where F_G is the total flux passed through the filter IF5148, and $F_{d,G}$ the flux of the continuum scattered by the dust particles. The total flux F_G is determined from the observed magnitude of the coma m_G,

$$F_G = F_{\odot,G}\times10^{0.4(m_{\odot,G}-m_G)} \tag{9}$$

where $F_{\odot,G}$ is the solar flux at 1 AU passed through the filter IF5148, and $m_{\odot,G}$ is the corresponding magnitude of the Sun. The second term in equation (8), $F_{d,G}$, is estimated from the flux as follows.

$$F_{d,G} = \frac{\int\sigma_G\varphi_G(\alpha)n(a)da}{\int\sigma_R\varphi_R(\alpha)n(a)da}F_R\,. \tag{10}$$

Substituting equations (9) and (10) into equation (8), the flux F_{C_2} is calculated. Then the magnitude m_{C_2} due to C_2 (0–0) band is estimated.

$$m_{C_2} = m_{\odot,G}+2.5\log F_{\odot,G}-2.5\log\{F_{\odot,G}\times10^{0.4(m_{\odot,G}-m_G)}-F_{\odot,R}\times10^{0.4(m_{\odot,R}-m_R)}\} \tag{11}$$

In equation (11) we assumed $F_{\odot,G}/F_{\odot,R}=1.4$. In table 3, we show m_{C_2} and magnitude H due to C_2 (0–0) emission at $\Delta=1$ AU.

The total mass of C_2 in the coma is estimated from the following equation (Sekanina, 1969);

$$M_{C_2} = 0.91\times10^{10}(r^2/f_{00})\times10^{-0.4H}\,, \tag{12}$$

where the heliocentric distance r is in AU, and f_{00} is the oscillator strength at C_2 (0–0) vibrational transition and is equal to 0.017 (A'Hearn and Cowan, 1975). Also C_2 production rate, $\dot{N}_{C_2}$, at the heliocentric distance r is approximated by

$$\dot{N}_{C_2} = M_{C_2}/4\times10^{-23}\tau\,, \tag{13}$$

where τ is the mean life time of C_2 in the coma, after Sekanina (1969),

$$\tau = \tau_0 r^2 \quad \text{and} \quad \tau_0 = 3\,(day\ AU^{-2}). \tag{14}$$

In the third and last columns of table 4, the total mass of C_2 and its production rate are shown. Mass and production rate of C_2 are 2.2×10^{10} g and 1.9×10^{27} molecules s^{-1} on March 25 (r=1.08 AU), and they reduced to 1.3×10^{9} and 6.9×10^{25}, respectively, on April 13 (r=1.37 AU).

5. Conclusion

In the preceding sections we estimated dust and C_2-contents in the coma observed on March 25 through April 13, 1986. The mass of dust on March 25 is 3.3×10^{13} g, and those of other days (March 31-April 13) are in order of 10^{12} g. We have no data in February, 1986, just after perihelion passage. However if we assume m_R=2.5 mag in late February, the mass of dust in the coma would be 10^{14} g. It is one order higher than that of Comet West 1976 VI which burst at the perihelion (Akabane, 1983).

The production rate of C_2 is 1.9×10^{27} molecules s^{-1} on March 25, 1.4×10^{26} on April 1, and 6.9×10^{25} on April 13, 1986. Vega-2 observation (March 9, 1986, r=0.83 AU) shows that the production rate of C_2 is 6×10^{27} molecules s^{-1} (Krasnopolsky et al., 1986). Our estimated values are consistent with the Vega-2 observation. Although the production rate of C_2 varies significantly with heliocentric distance, it was 10^{26} to 10^{27} for Comet Kohoutek 1973 XII, and 10^{24} to 10^{25} for P/Enke 1980 XI (Newbarn and Spinrad, 1984). The production rate of Halley's Comet (1986III) is the same order to that of Comet Kohoutek.

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