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Abstract

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DETERMINATION OF THE PHYSICAL CHARACTERISTICS OF THE CYANOGEN HALOS OF HALLEY' S COMET 1910 II

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1. Determination of the magnitude of the initial velocity and acceleration.

On the basis of observations one can obtain an idea of the initial velocities and accelerations of the molecules forming halos. For this purpose the materials cited by N. Bobrovnikov in the monograph (^6) (pp. 399–404) were used.

Let us first consider the observations for which no displacement of the halo center relative to the photometric center of the comet' s head was detected.

		Moment	Diameter
1910	May	31.279	$6',8$
		31.777	$8',5$
	June	2.685	$15',3$

Apparently we are dealing here with one and the same halo at different moments of its development. On the spectrogram of June 2 only the CN band (3883 Å) is noted, while on May 31, in addition to CN, C_2 (4737 Å) was also detected. The presence of C_2 radiation (4737 Å) can be explained by the fact that the halo was observed against the background of the comet' s head, in the spectrum of whose inner part this radiation is very often observed. The error in measuring the position of the details (according to Bobrovnikov' s estimate) is about $1'$.

For the moment 1910 May 31.5 the heliocentric distance of the comet is $r = 1.05$, and the geocentric distance is $\Delta = 0.47$ AU. Therefore the line of sight may be regarded as perpendicular to the comet' s radius vector, and the formulae obtained for the simplest halo model (^1) may be applied.

Taking $R = v_0 T$, we obtain for the above moments of observation

$$v^0 = 4.2 \cdot 10^4 \text{ cm/sec}$$

$$T_1 = 16.7 \cdot 10^4 \text{ sec}, \qquad T_2 = 21 \cdot 10^4 \text{ sec}, \qquad T_3 = 37.4 \cdot 10^4 \text{ sec}.$$

(v_0 is the initial velocity of the molecules forming the halo, and T_1, T_2, T_3 are the time intervals from the end of the explosion to the moment of observation.)

Assuming

$$T = \lambda \frac{v_0}{g}, \qquad \Delta T = \lambda' \frac{v_0}{g}, \tag{1}$$

we obtained ($\frown$1) for the maximum of the visible density in the halo

$$N_\Gamma = \frac{2ng}{v_0^3} \frac{\sqrt{2\lambda'}}{\lambda\sqrt{\lambda(1-\lambda)}}, \tag{2}$$

where the ratio of the displacement of the halo center to its radius is

$$\frac{|\Delta_c|}{R} = \frac{1}{2}\lambda.$$

Having good photometric observations that would allow a reliable estimate of the change in visible density with time, we could find the values of λ corresponding to the moments of observation, and calculate

acceleration g. Unfortunately, the observations required for this are lacking, and λ must be estimated in another way.

If we assume that at the moment T_2 we have $\lambda = 0.2$, and at the moment T_3, $\lambda = 0.36$, then at the moment T_3 the displacement of the halo center will be $1'.3$ —a value close to the measurement error. These values of λ are the largest for which a displacement of the halo center cannot be detected. The acceleration of the repulsive force corresponding to these values, $g = 0.04$ cm/sec^2, is the upper limit of the acceleration for the present case.

In Table 92 (p. 401) of the monograph (^{6}), measurements are given of one more halo from observations on May 31. With the diameter of the spectral image $18'.9$, the center is displaced by $1'.6$ (measurement of a photograph of this object gives a diameter of $17'.5$ and a displacement of the center of $2'.6$ for May 31.777). On June 2 this halo is not noted. If we regard it as similar to the one studied by us, since the spectra and the time of observation are the same, then, using the values of v_0 and g obtained by us, we find for the spectral image a displacement of the center equal to $2'.1$. The agreement of the calculated value with that obtained from the observations is satisfactory.

The value we obtained for the acceleration of the pressure of solar radiation on cyanogen molecules at a distance of 1.05 AU, $g = 0.04$ cm/sec^2, may be regarded as close to the true value, since it explains the impossibility of detecting the displacement of the center at the early stages of halo development, while at a later stage it gives for the displacement a value practically coinciding with the measured one.

If, on the basis of this value of g, taking the residual intensity in the vicinity of $\lambda 3883$ Å as equal to 20%, and the brightness temperature of the Sun as 5550° K, we determine the oscillator strength f_{12} from the formula

$$\frac{g}{g'} = c_1 \frac{f_{12}}{a} \frac{1}{e^{h\nu/kT} - 1} \cdot 0.2,$$

where g' is the acceleration of solar gravity (at a distance of 1.05, equal to 0.54 cm/sec^2), $c_1 = 4.4 \cdot 10^5$, $a = 26$, then we obtain

$$f_{12} \ll 2.1 \cdot 10^{-2}.$$

The value calculated by the methods of quantum mechanics (a rough estimate),

$$f_{12} = 2.6 \cdot 10^{-2}$$

is close to that obtained by us, which confirms the reality of the value $g = 0.04$.

2. On the possibility of estimating the masses of the halos. On the basis of photographs and information on spectra contained in the monograph (^{6}), it may be asserted that the halo studied by us was observed against the background of the comet' s cyanogen head.

The cyanogen component of the head of the comet of 1942, studied by B. A. Vorontsov-Vel' yaminov (^{2}), was a long-lived object. The apparent density in it obeyed the law

$$N_k = \frac{\pi n g}{v_0^3} \frac{1}{\sqrt{p^2 + q^2}}, \tag{3}$$

where $p = x\sqrt{\frac{v_0^2}{g}},\ q = y\sqrt{\frac{v_0^2}{g}}$. The dimensions of the head of the comet of 1942 were very large, and it may be assumed that at a heliocentric distance of 1.35 the abscissa of the vertex of the enveloping paraboloid was

$$x_0 = \frac{v_0^2}{2g} \simeq 5 \cdot 10^{11} \text{ cm}.$$

At a heliocentric distance of 1.05 it would be equal (for the same value of v_0 and an increased value of g) to

$$x_0 = \frac{v_0^2}{2g} \simeq 3 \cdot 10^{11}\ \text{cm}. \tag{a}$$

The heads of Halley' s comet and of the 1942 comet are similar in brightness to the spectrum, and if the cyanogen components of both comets are formed as a result of the same process, then for the head of Halley' s comet condition (a) must be satisfied. Since $g = 0.04$, from this condition we find the initial velocity of the molecules forming the head of Halley' s comet:

$$v_0 = 15.5 \cdot 10^4\ \text{cm/sec}.$$

Using all these assumptions, we obtain for the moment $T_2 = 21 \cdot 10^4$ sec: $x = 80 \cdot 10^8$ cm (the abscissa of the point of intersection of the edge of the halo with the radius vector), $p = 0.013$, $\lambda = 0.2$ ($q = 0,\ y = 0$).

The halo will be visible against the background of the head if

$$\frac{N_\Gamma}{N_\kappa} = 1. \tag{ }$$

Observing condition ( ), one can find the ratio of the emission coefficients from formulas (2) and (3)

$$\frac{n_\Gamma}{n_\kappa} = \frac{\pi}{2} \left(\frac{v_{0\Gamma}}{v_{0\kappa}} \right)^2 \frac{\lambda \sqrt{\lambda(1-\lambda)}}{p\sqrt{2\lambda'}}. \tag{4}$$

(The values of the repulsive force for the molecule in the head and in the halo are the same.)

Substituting the numerical values into formula (4), we obtain for the moment T_2

$$n_\Gamma = \frac{0.135}{\sqrt{\lambda'}} n_\kappa. \tag{5}$$

At present the processes as a result of which the halo is formed are unknown; therefore an estimate of the quantity λ' is not yet possible. In deriving formula (2) we only assumed $\lambda' \ll \lambda$.

If we take $\lambda' = 0.002$ ($\Delta T = 2100$ sec), then by formula (5)

$$n_\Gamma = 3 n_\kappa,$$

and if $\lambda' = 2 \cdot 10^{-5}$ ($\Delta T = 21$ sec), then

$$n_\Gamma = 30 n_\kappa .$$

The emission coefficients n_κ can be determined if the number of molecules inside a definite isophote in the head of the comet at the moment of observation is known. B. A. Vorontsov-Velyaminov (^{3}) obtained for the 1942 comet, inside a circular isophote with radius $x_0/10$, $1.3 \cdot 10^{33}$ CN molecules. We shall take the same value also for Halley' s comet, since their brightnesses are almost equal. Then

$$\iint_{(\sigma)} N dx\, dy = 1.3 \cdot 10^{33} \text{ molecules}$$

(the region of integration is a circle with radius $v_0^2/20g$). Since

$$N = \frac{\pi n_\kappa}{v_0} \frac{1}{\sqrt{x^2+y^2}},$$

we obtain

$$\frac{\pi^2 n_\kappa v_0}{10g} = 1.3 \cdot 10^{33}$$

or

$$n_\kappa = 3 \cdot 10^{26} \text{ molecules/sec} \cdot \text{sterad.}$$

For the halo

$$\begin{aligned} &\text{at } \Delta T = 2100 \text{ sec.} \quad n_\Gamma = 9 \cdot 10^{26}, \\ &\text{at } \Delta T = 21 \text{ sec.} \quad n_\Gamma = 9 \cdot 10^{27}. \end{aligned}$$

The number of molecules in the halo N_1 and its mass m:

$$\begin{aligned} &\text{for } \Delta T = 2100 \text{ sec.} \quad N_1 = 24 \cdot 10^{30}, \quad m = 10^9 \text{ g}, \\ &\text{for } \Delta T = \quad 12 \text{ sec.} \quad N_1 = 24 \cdot 10^{29}, \quad m = 10^8 \text{ g}, \end{aligned}$$

therefore, the mass of the halo is 2–3 orders of magnitude smaller than the mass of the cyanogen head of the comet, calculated on the basis of the value of the number of molecules in the head derived by B. A. Vorontsov-Vel' yaminov.

Conclusion. The values we have found from observations of the cyanogen halos of Halley' s comet for the initial velocity v_0 and the acceleration due to light pressure g may be regarded as close to the truth, but the numbers characterizing the mass and the emission coefficient of the halos cannot be so regarded. The calculations in the latter case were based on the assumption of similarity between the cyanogen head of Halley' s comet and that of comet 1942 g, which, of course, casts doubt on the reliability of the results.

It is interesting to note that the value of g obtained by us differs by almost a factor of 10 from that found by fitting in 1958. (^{5}) This is due to the fact that in the materials used in 1958 it was not possible to use criteria that make the calculations more probable and control them. But we see that theory would have made it possible, even at the present level of development, to compute these quantities if we had observations suitable for absolute photometry through a filter transmitting the spectral region near λ 3883 Å. At the same time, it would have been extremely important to have data on the brightness gradient; this would even have helped to estimate the magnitude λ'.

Unfortunately, the gradient was first determined only from photographs of comet 1957 d (Mrkos) at the Byurakan Observatory by L. V. Mirzoyan and E. E. Khachikyan (^{4}). This interesting photometric material can be correctly interpreted only with further development of the theory of cometary forms, when the effect of the comet' s motion in its orbit will be taken into account (the isophotes are asymmetric with respect to the radius vector of the comet). There were no halos in the photographs of the Byurakan astronomers, and their studies could not be used in this direction. But these studies may be regarded as a starting example for observers in the future, while at present they require development of the theory of cometary forms and an explanation of the asymmetry of the isophotes in the head of the comet. It should be noted that such studies will become more valuable and more convenient for processing if absolute photometry is carried out on images obtained through filters in the regions of CH (3883 Å), C_2 (4737 Å), and other cometary emissions.

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Note: Figure translations are in progress. See original paper for figures.